AD-A120 080 MITRE CORP MCLEAN VA METREK DIV F/G 17/7
CONFLICT MONITORING ANALYSIS OF PARALLEL OPPOSITE DIRECTION ROU--ETC(U)
AUG 82 A P SMITH DTFA01-82-C-10003
UNCLASSIFIED MTR-82W00114-VOL-1 FAA-EM-83-23-VOL-1 NL

1 OF 1
A
120080

END
DATE
FILMED
11 82
DTIC

Report No. FAA-EM-82-23
Volume I

(12)

[illegible]
Volume I

CONFLICT MONITORING ANALYSIS OF PARALLEL OPPOSITE DIRECTION ROUTES

Arthur P. Smith, III

The MITRE Corporation
McLean, Virginia 22102

AUGUST 1982

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
OFFICE OF SYSTEMS ENGINEERING MANAGEMENT
Washington, D.C. 20591

Technical Report Documentation Page

1. Report No. FAA-EM-82-23	2. Government Accession No. AD-A120 080	3. Recipient's Catalog No.
4. Title and Subtitle Conflict Monitoring Analysis of Parallel Opposite Direction Routes		5. Report Date August 1982
		6. Performing Organization Code
7. Author(s) Arthur P. Smith, III		8. Performing Organization Report No. MTR-82W00114, Volume I
9. Performing Organization Name and Address The MITRE Corporation Metrek Division 1820 Dolley Madison Boulevard McLean, Virginia 22102		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFA01-82-C10003
12. Sponsoring Agency Name and Address Office of Systems Engineering Management Federal Aviation Administration Department of Transportation Washington, D.C. 20591		13. Type of Report and Period Covered
		14. Sponsoring Agency Code DOT/FAA
15. Supplementary Notes		

16. Abstract

This paper reports on the development of the Conflict Monitoring Analysis. A previous report (FAA-EM-80-16) described the estimates of the probability of horizontal overlap and controller intervention rate for same direction adjacent parallel routes. This work extends that methodology to opposite direction adjacent parallel routes. For both the probability of horizontal overlap and the controller intervention rate, trial results based on data are given.

A

17. Key Words Collision Risk Methodology Safety Controller Intervention Rate VOR Route Spacing Aircraft Separation	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

SUMMARY

This report describes work completed since the last interim report on the Conflict Monitoring Parallel Route Spacing Analysis for Same Direction Traffic(7). The analysis reported here was performed to assess the potential for collision and the controller workload associated with aircraft flying on opposite direction parallel routes in the high altitude CONUS airspace with a controller monitoring the aircraft with radar. The analysis has two parts. The first part is an estimate of the potential for collision while the second part is an estimate of the controller intervention rate.

BACKGROUND

In November 1976, the FAA Associate Administrator for Air Traffic and Airway Facilities requested assistance from the Associate Administrator for Engineering and Development in certain analytical activities relating to air traffic separation. In part, that request asked for an examination of the soundness of the current standards for the horizontal separation of aircraft in the continental U.S. The request also called for an enhancement of analytical methods for the operational evaluation of future standards.

In response to that request a program was initiated within the FAA's Office of Systems Engineering Managment (AEM-100) to study VOR-defined air route separation. Improved specifications of navigation and control system performance needed to support specific route spacings are to be developed as part of this effort.

The FAA's VOR-defined air route separation program involved a data collection followed by analytical activities. Concurrent with the data collection, several analyses were performed which addressed the relationship of navigation and ATC system performance to safety of operations on the VOR route system. These analyses addressed the potential for collision between aircraft assigned to different routes under various conditions. One analysis(3) addressed the potential for collision between aircraft assigned to parallel routes under the assumption that no radar was used to separate the aircraft. Another analysis, performed by MITRE(7), addressed the potential for collision and the controller intervention rate for aircraft assigned to same direction parallel routes when the controller monitors aircraft movements with radar surveillance.

The status of the data collection and analytical activities was periodically reported to the Separation Study Review Group (SSRG) between March 1977 and December 1980. This group was formed by the Executive Committee of the Radio Technical Commission for Aeronautics (RTCA) and was charged with reviewing and commenting on the FAA's air route separation program. Currently, the participants in the FAA's VOR-defined route separation program are working in committee to restructure the route separation criteria. This activity has just begun.

APPROACH

The measures of performance which are used in this report which relate to the potential for collisions and the workload are the probability of horizontal overlap and the controller intervention rate, respectively.

The FAA has adopted the probablity of horizontal overlap as the measure of the potential for collision. The probability of horizontal overlap is based on a calculation of the chance that aircraft will come very close to one another, due to loss of lateral separation, averaged over a very long interval of flying hours on parallel routes. This calculation is necessarily based on a number of bounding arguments and assumptions as to how the system will behave. These assumptions provide high estimates (i.e, pessimistic) of the long-term probability of horizontal overlap for systems that are operating under normal (non-failure) conditions and for aircraft that are maintaining their centerline with the accuracy observed on selected routes in the U. S. Other measures for the potential of collision that reflect system performance in specific situations such as surveillance system outages and situations where aircraft are involved in conflicts due to gross navigation errors will be examined in later phases of this study.

If there is radar surveillance, then an estimate of workload on the controller and the pilot because of the surveillance function is needed. The workload estimator was chosen to be the controller intervention rate. The controller intervention rate was chosen because it is easily translated into a pilot workload measure, i.e., the number of hours between alerts for a pilot.

THE PROBABILITY OF HORIZONTAL OVERLAP ANALYSIS

In the current high altitude CONUS airspace, lateral separation is nominally provided by a non-radar procedure even though the aircraft are operating in a radar environment with "radar contact"

established. The controller will separate aircraft laterally by clearing them to different routes and when he perceives a potential violation of the radar separation minima he will take corrective action. Although the normal practice of controllers is not to clear opposite direction traffic on adjacent routes at the same flight level, such clearances do in fact happen and the aircraft are still considered to be separated laterally.

When considering the controller's action in separating aircraft, one of the primary issues is the point in time when the controller performs the control action. The time of perception of a conflict will vary from controller to controller. To define this time more explicitly we have chosen to consider the time at which the NAS Conflict Alert would alert the controller to a potential conflict.

Once a pair of aircraft have the separation and closing speed that should generate a conflict alert there could be a delay before a resolution action is taken. This delay includes:

1. The time due to surveillance errors and tracker lag for the conflict alert function to recognize the potential conflict,

2. The reaction time of the controller to recognize the situation, formulate a solution, seize a communication channel, and

3. The time required for the pilot to become cognizant of the situation and to initiate the resolution maneuver.

The resolution maneuver is assumed to be a single coordinated horizontal turn by one of the aircraft in conflict. The sense of the turn is selected in this analysis in a manner suggested by the Conflict Resolution Advisory function under development for the NAS. For those aircraft that are near enough to each other to generate a conflict alert, the analysis estimates the probability that the aircraft will collide. This probability of collision is based on the limited resolution scenario adopted for this analysis: a single aircraft executing a horizontal turn after a random delay time. The use of a single horizontal turn by a single aircraft was motivated by the desire to take a very conservative estimate of the effects of controller monitoring. In many potential conflict situations with opposite direction traffic, horizontal turns by both aircraft or a vertical maneuver by one or both may be selected by the controller if the situation is perceived to require it.

Data on the crosstrack deviations and crosstrack velocities of

individual aircraft flying selected high altitude routes were used to estimate the joint probability of separation and closing speeds between pairs of aircraft. This joint probability estimate was used in the analysis to indicate the occurrence of potentially conflicting pairs of aircraft. This coupled with the aforementioned delay and resolution maneuver results in a conservative estimation of the probability of horizontal overlap.

THE INTERVENTION RATE ANALYSIS

In order to investigate the rate at which the alerts would be generated a simulation was performed. The simulation used a sample of smoothed radar tracks of aircraft obtained during the FAA'a data collection. The entry times of the aircraft were chosen randomly based on the desired traffic loading.

Since the tracks from the FAA's data collection were smoothed to remove the radar errors, radar errors had to be added to the track data during the simulation. This was accomplished by choosing a radar site and adding range and azimuth errors to each aircraft position report. The errors that were used were representative of the FAA radar beacon systems.

At each radar update time a set of radar returns from every aircraft currently on the routes was processed. This processing included tracking the returns through an emulation of the NAS tracker, and then using the tracker position and velocity estimates in the conflict alert function.

Once an aircraft pair received an alert in the simulation, that pair was no longer considered for additional alerts. Furthermore, no attempt was made to realign the tracks of alerted aircraft to account for any response to controller interventions. This means that in the analysis a given aircraft pair can be detected in potential conflict only once in the sector of interest. However, the fact that a particular aircraft received an alert with one aircraft did not preclude it from receiving alerts involving other aircraft as it progressed through the sector.

The output from the simulation was an estimate of the number of conflict alerts per sector hour.

TRIAL RESULTS

The opposite direction analyses were performed with a subset of the lateral pathkeeping performance data collected by the FAA in the

Cleveland ARTCC in 1977 and 1978. For the probability of horizontal overlap analysis, data was used that reflected lateral deviations and lateral speeds experienced by aircraft 50 nmi from the VOR. For the controller intervention analysis a randomly selected set of 200 flights were chosen and their entire flight track history in the sectors of interest was used to estimate the frequency of conflict alerts. These data are preliminary in nature, and while the analyses give an indication of the potential of collision and controller workload associated with a parallel route system, the analyses must be performed with data that reflect pathkeeping performance at greater distances from the VOR and in other ARTCCs. Such data has been prepared by the FAA.

Because of the infrequent use of non-cardinal altitudes, particularly in the presence of opposite direction traffic on an adjacent route, it is difficult to estimate representative flow rates for a typical pair of routes. In the Cleveland ARTCC, the frequency that adjacent routes were simultaneously used for opposite direction, coaltitude flows was quite low. This resulted in an observed probability of 5.1×10^{-6} that an aircraft would find an opposite direction aircraft within a short along-track distance on the adjacent route at his assigned altitude.(Reference 3) This probability is referred to as the probability of longitudinal overlap, P_x, and is a key factor in the determination of the probability of horizontal overlap. The analysis presented here will consider the opposite direction flows, expressed in terms of P_x, that can be supported by conflict monitoring and by procedural control. For the purposes of illustration, a flow rate can be supported if the probability of horizontal overlap is below that required to be consistent with the safety level deemed to be minimally acceptable in a number of recent U.S. studies, including the establishment of the Central East Pacific route system [11] and the revised ground obstruction clearance requirements.[12] Figure 1 shows the supportable flow rates in a conflict monitoring environment and in a procedural environment.

As seen in Figure 1, conflict monitoring is estimated to support the opposite direction flow rates observed in Cleveland on parallel routes spaced as closely as 8 nmi. Procedural control would support spacings in excess of 15 nmi. In the conflict monitoring analysis shown in Figure 1 it was assumed that the controller would resolve the conflict through selection of a turn with the minimal heading change to assure safe passage and that the aircraft would execute a relatively sharp turn (25° to 30° bank angle). The effectiveness of other resolutions are discussed in Section 4 of this report.

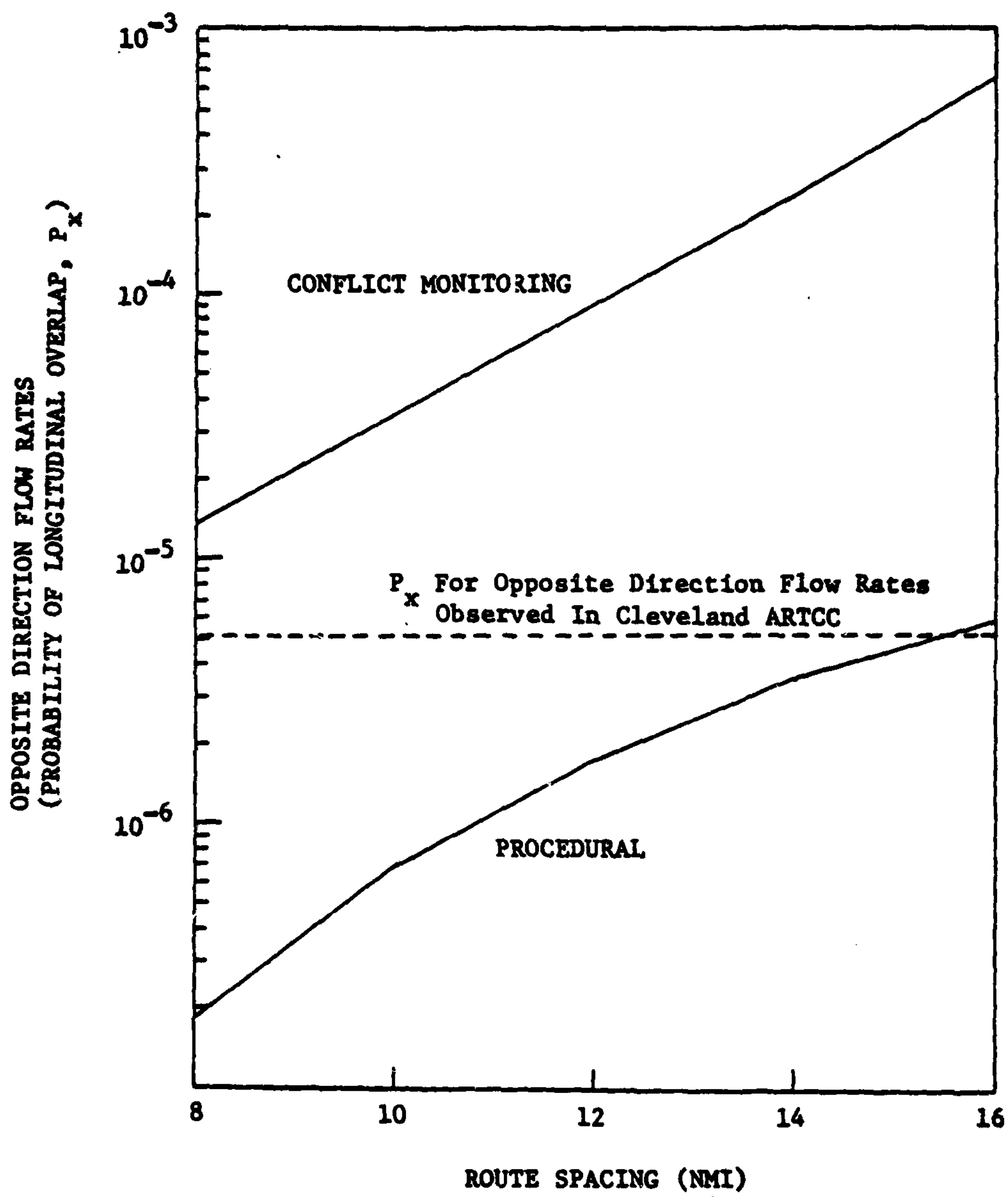


FIGURE 1
SUPPORTABLE OPPOSITE DIRECTION FLOWS

The intervention rate was estimated from the simulation described above. The simulation was replicated ten times, each replication representing different sequences of aircraft that fly through the sector. The results of the simulation for the exceptionally high traffic loading of five aircraft per hour operating at the same assigned altitude on each of the adjacent routes shows that for an 8 nmi route spacing an average of 1.5 alerts per hour would be expected. The results of the intervention rate simulation are shown in Figure 2.

The results previously discussed are interim in nature as they are based on available data on VOR pathkeeping performance in one ARTCC and do not address some of the infrequent but important cases where the aircraft are turning when they are detected to be in potential conflict. Such conflicts are more difficult to detect and resolve than the encounters involving strictly a straight and level flight. Those conflicts involving small lateral accelerations are the subject of continuing study in this task. In addition, the results to date have considered the likelihood of aircraft coming close together averaged over a broad range of conflict geometries. Attention must also be given to the degree to which the control system can resolve specific extreme encounters. All of these efforts are to be addressed as part of the ongoing work to develop revised criteria for the establishment of parallel VOR routes.

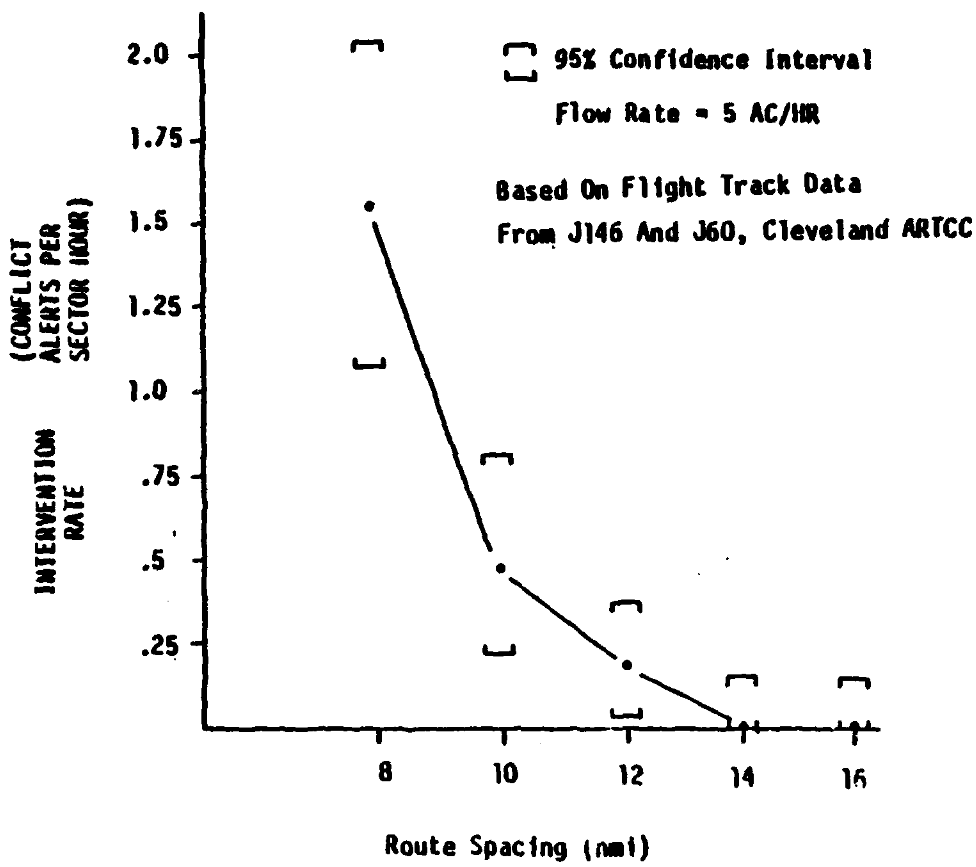


FIGURE 2
OPPOSITE DIRECTION INTERVENTION RATE RESULTS

TABLE OF CONTENTS

		Page
1.	INTRODUCTION	1-1
1.1	Background	1-1
1.2	Analysis of Parallel Routes with Same Direction Traffic Flows	1-2
1.3	Analysis of Parallel Routes with Opposite Direction Traffic Flows	1-2
1.4	Report Organization	1-3
2.	HORIZONTAL OVERLAP ANALYSIS	2-1
2.1	Conflict Scenario	2-1
2.2	Assumptions	2-3
2.2.1	Accelerations	2-5
2.2.2	Resolution Maneuvers	2-5
2.3	Horizontal Overlap Analysis	2-5
2.3.1	Data	2-5
2.3.2	The Conflict Surface	2-10
2.3.3	Delay Modelling	2-15
2.3.4	Resolution Modelling	2-15
2.3.4.1	Turn Sense	2-18
2.3.4.2	Probability of Improper Turn Sense	2-18
2.3.4.3	Overlap Region	2-20
2.3.5	Probability of Horizontal Overlap	2-23
3.	INTERVENTION RATE ANALYSIS	3-1
3.1	The Simulation Approach	3-1
3.2	Limits Imposed On the Horizontal Overlap Analysis by the Intervention Rate	3-3
4.	TRIAL RESULTS	4-1
4.1	Horizontal Overlap Analysis Results	4-1
4.1.1	Inputs	4-1
4.1.2	Results	4-5

TABLE OF CONTENTS
(Concluded)

	Page
4.2 Intervention Rate Analysis Results	4-7
4.2.1 Inputs	4-7
4.2.2 Results	4-9
5. RECOMMENDATIONS	5-1
5.1 Conflict Monitoring Analysis Development	5-1
5.2 Use of the Analysis	5-1
5.3 Additional Areas of Investigation	5-1
APPENDIX A: REFERENCES	A-1

LIST OF ILLUSTRATIONS

		Page
TABLE 2-1	SURVEILLANCE/TRACKER INPUT PARAMETERS	2-11
TABLE 4-1	INPUT TO PROBABILITY OF HORIZONTAL OVERLAP ANALYSIS	4-2
FIGURE 2-1	OPPOSITE DIRECTION CONFLICT MONITORING HORIZONTAL OVERLAP ANALYSIS	2-2
FIGURE 2-2	CONFLICT SCENARIO ON OPPOSITE DIRECTION ROUTES	2-4
FIGURE 2-3	JOINT PROBABILITY HISTOGRAM OF CROSSTRACK SEPARATION AND CLOSING SPEED	2-7
FIGURE 2-4	AVERAGE RELATIVE CROSSTRACK ACCELERATION HISTOGRAM	2-8
FIGURE 2-5	REACTION/COMMUNICATION TIME DELAY HISTOGRAM	2-9
FIGURE 2-6	TURN RATE HISTOGRAM	2-12
FIGURE 2-7	CONFLICT SURFACE	2-14
FIGURE 2-8	DETECTION DELAY TIME HISTOGRAM	2-16
FIGURE 2-9	TOTAL TIME DELAY HISTOGRAM	2-17
FIGURE 2-10	PROHIBITED HEADINGS	2-19
FIGURE 2-11	PROPER TURN SENSE PROBABILITY	2-21
FIGURE 2-12	HORIZONTAL OVERLAP REGION	2-22
FIGURE 3-1	INTERVENTION RATE SIMULATION	3-2
FIGURE 4-1	SUPPORTABLE OPPOSITE DIRECTION FLOWS	4-6
FIGURE 4-2	ROUTE STRUCTURE FOR OPPOSITE DIRECTION INTERVENTION RATE SIMULATION	4-8
FIGURE 4-3	OPPOSITE DIRECTION INTERVENTION RATE RESULTS	4-10

1. INTRODUCTION

1.1 Background

In November 1976, the FAA Associate Administrator for Air Traffic and Airway Facilities requested assistance from the Associate Administrator for Engineering and Development in certain analytical activities relating to air traffic separation.(1) In part, that request asked for an examination of the soundness of the current standards for the horizontal separation of aircraft in the continental U.S. The request also called for an enhancement of analytical methods for the operational evaluation of future standards. In response to that request a program was initiated within the FAA's Office of Systems Engineering Management (AEM-100) to study the separation of VOR-defined air routes.

This study's goal is to develop criteria for the establishment of VOR routes. An FAA committee has been formed to fulfill this objective. The committee is composed of representatives from the Office of Systems Engineering Management, Air Traffic Service, Airway Facilities, the Technical Center, and MITRE. The system being addressed consists of both the airborne and ground elements of navigation and air traffic control. After the safety/performance relationship is established, the committee will propose improved specifications of navigation and control system performance needed to support specific route spacings.

The FAA's VOR-defined air route separation program is based on a data collection followed by modelling and analytical activities. The data collection was conducted by the FAA Technical Center (ACT-220) from September 1977 to April 1978. (2) A data base has been compiled from the 1977-1978 data collection. Concurrent with the data collection, there were several analyses performed which addressed the relationship of navigation and ATC system performance to safety of operations on the VOR route system. These analyses addressed the potential for collision between aircraft assigned to different routes under various conditions. The Technical Center's analysis addressed the potential for collision between aircraft assigned to parallel routes under the assumption that there is no radar being used to separate the aircraft.(3) There was also an effort at Princeton University to address the potential for collision of aircraft on intersecting routes where no radar coverage is available.(4)

The status of the data collection and analytical activities were periodically reported to the Separation Study Review Group (SSRG) from March 1977 through December 1980. This group was formed by the Executive Committee of the Radio Technical Commission for Aeronautics (RTCA) and was charged with reviewing and commenting on the FAA's air route separation program.[5] This group reviewed the data and recommended the completion of the analytical studies.[6]

1.2 Analysis of Parallel Routes with Same Direction Traffic Flows

In conjunction with the VOR-defined air route separation program MITRE performed an analysis which addressed the potential for collision and the controller intervention rate in a conflict monitoring environment for aircraft assigned to same direction parallel routes.[7] Under the conservative assumptions made in that analysis and using preliminary data, the probability of horizontal overlap estimates were estimated to be several orders of magnitude below the conservative estimates of the probability of horizontal overlap produced by the procedural analysis. The results of the intervention rate simulation for a relatively high traffic loading of five aircraft per hour operating at the same assigned altitude in the same direction on each of the adjacent routes show that for an 8 nmi route spacing on average less than 1 alert per two hours of sector operation would be expected.

1.3 Analysis of Parallel Routes with Opposite Direction Traffic Flows

Whereas the previous MITRE analysis considered the conflict monitoring environment with same direction parallel routes, the analysis reported in this paper extends that analysis to opposite direction parallel routes. The basic difference between these two analyses is the nature of the encounters between the aircraft pairs. In the same direction analysis the aircraft were assumed to have approximately the same alongtrack speed. The encounter was modelled as a pair of aircraft that are randomly placed near each other in the alongtrack dimension. In the opposite direction analysis each pair of interest is going to pass. Therefore the encounter is modelled as a pair of aircraft that start a certain distance from each other, fly toward each other with a high closing speed and eventually pass.

The environment being considered is the same as that analyzed in

Reference 7 for the same direction routes with the exception of the direction of flight. The environment is the high altitude (above 24,000 feet) CONUS airspace. More specifically, opposite direction parallel routes having no transitioning traffic are considered. It is also assumed that there is complete radar coverage and the mechanism which will limit collisions is the controller interventions when aircraft come into apparent conflict. The Conflict Alert function in this analysis is used as a bound on the actual behavior of the controller. It is assumed that in most cases the controller will detect potential conflicts in advance of the Conflict Alert alarm and thus have more time to resolve the potential conflict.

As in the same direction analysis two characteristics of system performance will be considered. They are the potential for collision and the workload associated with the controller resolving the aircraft pairs in potential conflict. The measure for collision potential is the probability of horizontal overlap. The development of an estimate of the probability of horizontal overlap is discussed in Section 2 of this report. The measure for workload was chosen to be frequency of the controller interventions per hour of sector operation. The estimate of the controller intervention rate is discussed in Section 3 of this report.

1.4 Report Organization

This report will describe the methodology used to analyze opposite direction traffic flows on parallel routes. In order to avoid duplication of previous documentation, elements that are common with the same direction analysis will not be repeated. The pertinent results previously documented in Reference 7 will be cited. Additional methodological details that are unique to the opposite direction analyses will be documented in a supplement to this report.[8] Unless otherwise noted, Appendices referred to in this report will be included in that supplement.

2. HORIZONTAL OVERLAP ANALYSIS

This section will describe the methodology used to estimate the probability of horizontal overlap when there is a controller monitoring the air routes using radar surveillance. This analysis will be referred to as the Conflict Monitoring Analysis. It can be shown that the probability of horizontal overlap will be high for higher density, closely spaced routes if radar surveillance is not used. Since the probability of horizontal overlap is dictated by those aircraft which could get near to each other, it is the objective of the Conflict Monitoring Analysis to identify those aircraft which could be affected by controller interventions and to adjust the estimate for the probability of horizontal overlap by accounting for conflict resolution maneuvers. It should be noted that the analysis assumes that even with controller intervention there will still be some cases where the conflict detection process may occur too late or the resolution maneuver may be inadequate.

This section will describe the estimation of the value of the probability of horizontal overlap, P_H. The process through which P_H is estimated is shown in Figure 2-1. Each step in the process is identified with the section in which it is discussed. The probability of horizontal overlap depends on the probabilities of 1) having a specific initial conflict geometry, 2) having a given specific turn rate, and 3) having waited a length of time before turning. These probabilities, in turn, are estimated from VOR pathkeeping data, surveillance/tracking system performances measures, and assumptions relating to the turn rates and reaction delays.

2.1 Conflict Scenario

In the current high altitude CONUS airspace, lateral separation is nominally provided by a nonradar procedure even though the aircraft are operating in a radar environment with "radar contact" established. The controller will separate aircraft laterally by clearing them to different routes and when he perceives a potential violation of the radar separation minima he will apply radar separation.

When considering the controller's action in separating aircraft, one of the primary issues is the point in time that the controller performs the control action. The time of perception of a conflict will vary from controller to controller. To define this time more explicitly we have chosen to consider the time at which the NAS Conflict Alert would alert the controller to a potential conflict.

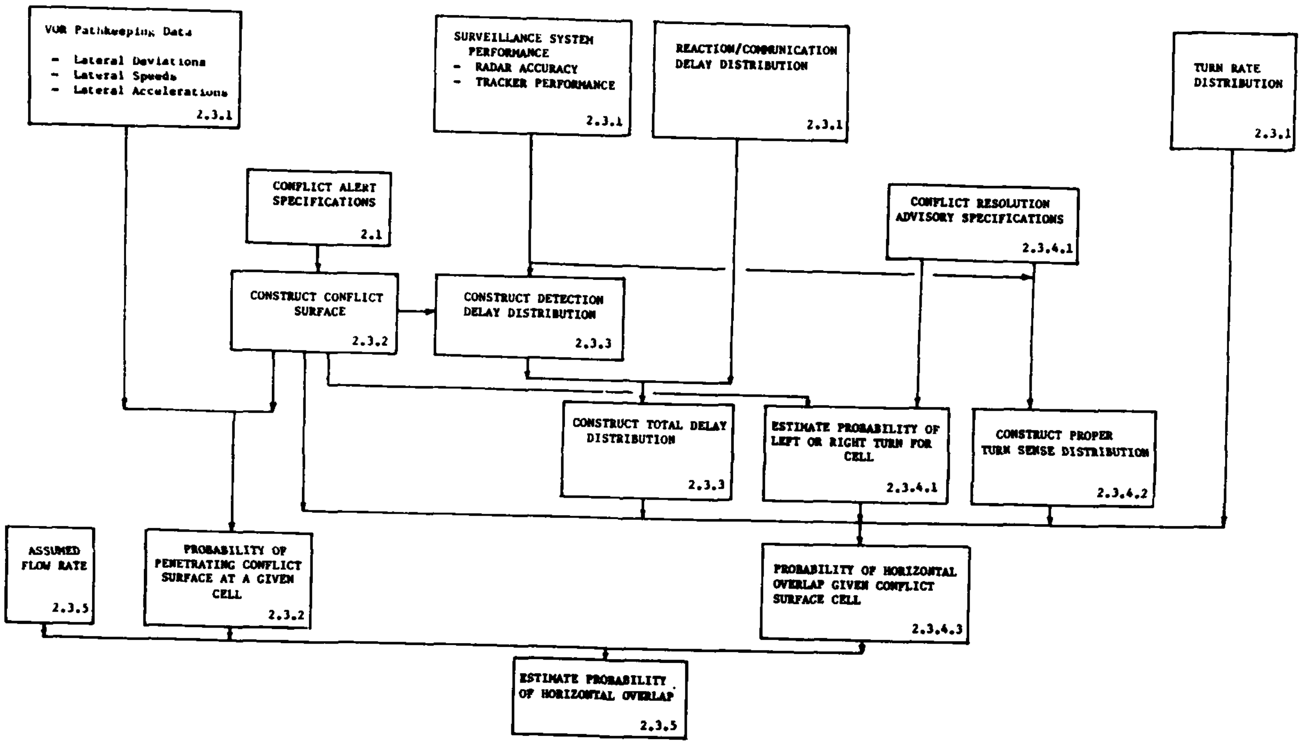


FIGURE 2-1
OPPOSITE DIRECTION CONFLICT MONITORING
HORIZONTAL OVERLAP ANALYSIS

The controller, in providing separation between aircraft, is expected to anticipate the situation (i.e., to look ahead farther in time than the automated Conflict Alert) and take steps to resolve a potential conflict before a Conflict Alert is displayed. Therefore, if the NAS Conflict Alert is properly designed it would tend to alert at a time later than the controller would normally perceive the conflict and resolve it. Given that the controller would normally perceive a potential conflict with more lead time than is provided by Conflict Alert, it follows that the controller-initiated action should result in less risk of collision than a later Conflict Alert-initiated maneuver. If the NAS Conflict Alert is available, then the perception of a potential conflict will be no later than the automatic alarm and the risk of collision will be no greater than that due to initiating a resolution action at the time of the automatic conflict alert. Therefore, the NAS Conflict Alert function will be used in this analysis as a conservative indicator of the time that a potential conflict is perceived by the controller.

In this analysis we are considering aircraft on adjacent routes that are in straight and level flight in opposite directions. Because of the cardinal altitude assignment scheme in the high altitude airspace, aircraft flying in opposite directions are rarely assigned the same altitude. However, in the FAA's VOR data collection there were a small number of aircraft observed flying in a direction opposite to that of the predominant traffic flow at the same altitude on the adjacent route.

The opposite direction conflict scenario is pictured in Figure 2-2. At time T_1 the aircraft on route 1 is heading away from its assigned route centerline such that in two minutes the aircraft will be exactly 5 nmi apart. At time T_1 the aircraft are said to be on the conflict boundary. After the aircraft pair passes through the conflict boundary there is a delay followed by a turn to resolve the conflict. The minimum distance between the aircraft after such a maneuver determines whether the aircraft will be in "overlap".

2.2 Assumptions

In the analysis of the probability of horizontal overlap for aircraft flying in the same direction on adjacent routes, several assumptions were made concerning the dynamics of flight and the response of the air traffic control system. Most, but not all, of the same direction analysis assumptions are carried

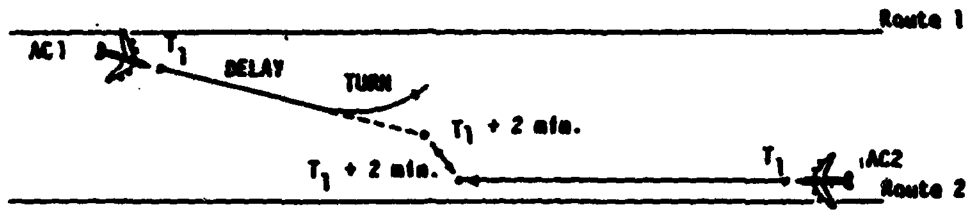


FIGURE 2-2
CONFLICT SCENARIO ON
OPPOSITE DIRECTION ROUTES

over to the opposite direction analysis. The assumptions that have been changed are discussed in this section. The common assumptions are stated in Section 3 of Reference 7.

2.2.1 Accelerations

The same direction analysis assumed that conflicting pairs of aircraft were not executing turns at the time the conflict was detected. In other words, both aircraft were assumed to fly in a straight line until the controller commanded one of the pilots to turn his aircraft back toward his assigned route centerline. In the opposite direction scenario provisions have been made to assume that the aircraft could have lateral accelerations, because it was found that certain conflict geometries that can realistically be expected to occur cannot be realized without assuming acceleration. The results presented in this interim report do not consider conflict encounters involving turning aircraft because the required computational procedures have not been completed. Results for this case will be presented in a later report.

2.2.2 Resolution Maneuvers

The assumption in the same direction analysis was that the maneuvering aircraft would always return to its assigned route centerline. In the opposite direction case this maneuver is not always the appropriate one. The direction of the turn will be chosen to be consistent with the Conflict Resolution logic being developed by the FAA for implementation in the ATC system.[9] In general the Conflict Resolution logic selects the turn direction that requires the smallest heading change to achieve a projected miss distance.

2.3 Horizontal Overlap Analysis

This section will describe the analysis which is performed to estimate the probability of horizontal overlap in a conflict monitoring environment for opposite direction traffic flows. The data needed for this analysis will be discussed followed by a brief description of the computational scheme.

2.3.1 Data

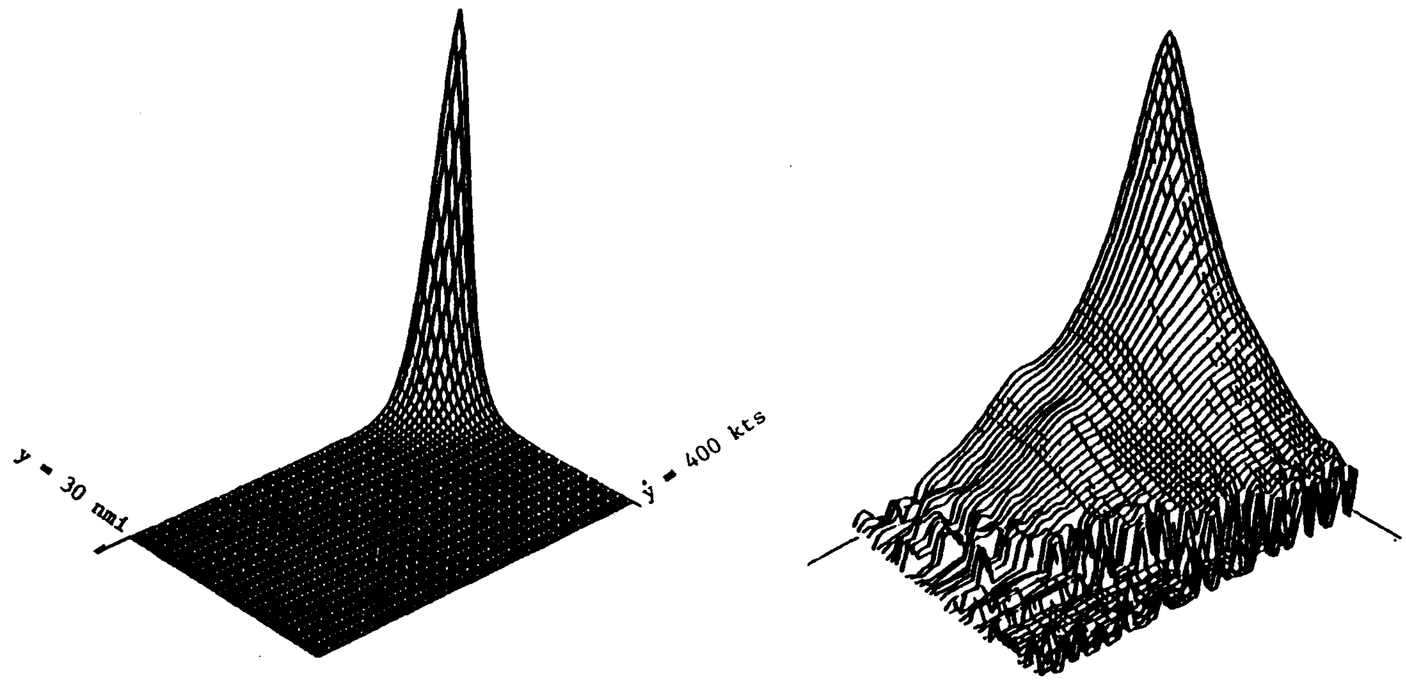
The required data for this analysis are shown in the top row of

boxes in Figure 2-1. First, data on the lateral pathkeeping performance with respect to the assigned routes are needed. From these data the probabilities of getting into the various conflict geometries can be estimated. The required form of these data is a lateral separation, lateral closing speed histogram and an average relative lateral acceleration histogram. The construction of the joint lateral separation/lateral closing speed histogram from the single aircraft data taken in the FAA's VOR pathkeeping data collection is described in Appendix F of Volume II of Reference 7. To give an impression of what such a joint histogram looks like, Figure 2-3 shows two representations of the histogram. In Figure 2-3a we see one quadrant of the symmetric joint histogram derived from the data taken 50 nmi from selected VORs in the Cleveland ARTCC. The y axis is the lateral separation, the peak being at the route spacing value. The $\dot{y}$ axis is the lateral closing speed, the peak being at the value of zero. As one expects, this histogram shows that most of the aircraft are separated by a distance equal to the route spacing and they tend to fly parallel to each other ($\dot{y} = 0$). To get an impression of the details of this histogram Figure 2-3b shows the histogram with a rescaled vertical axis. As the y and $\dot{y}$ values increase the data become more sparse, as one would expect.

The construction of the histogram of the average relative lateral accelerations from the data is described in Appendix A of this report.[8] Figure 2-4 shows the acceleration histogram that corresponds to the lateral separation/lateral closing speed histogram in Figure 2-3. As one can see, the average relative acceleration is mostly zero with the extreme average accelerations being about 0.1 g. It is assumed in the analysis that this acceleration is divided equally between the two aircraft on the adjacent opposite direction routes.

The controller/pilot reaction delay data which includes the communication time delay was taken from the simulation results in Reference 10. The details of this time delay are addressed in Appendix B of Volume II of Reference 7. The simulation results were fit with a gamma function and the result is shown in Figure 2-5.

The analyses of the conflict monitoring environment include the errors of the surveillance and tracking systems. The errors in this case are represented as correlated quadrivariate normal variates in alongtrack separation, crosstrack separation, crosstrack closing speed and the crosstrack speed of one of the aircraft. The distribution of these errors was estimated via



a

b

FIGURE 2-3
JOINT PROBABILITY HISTOGRAM OF
CROSSTRACK SEPARATION AND CLOSING SPEED

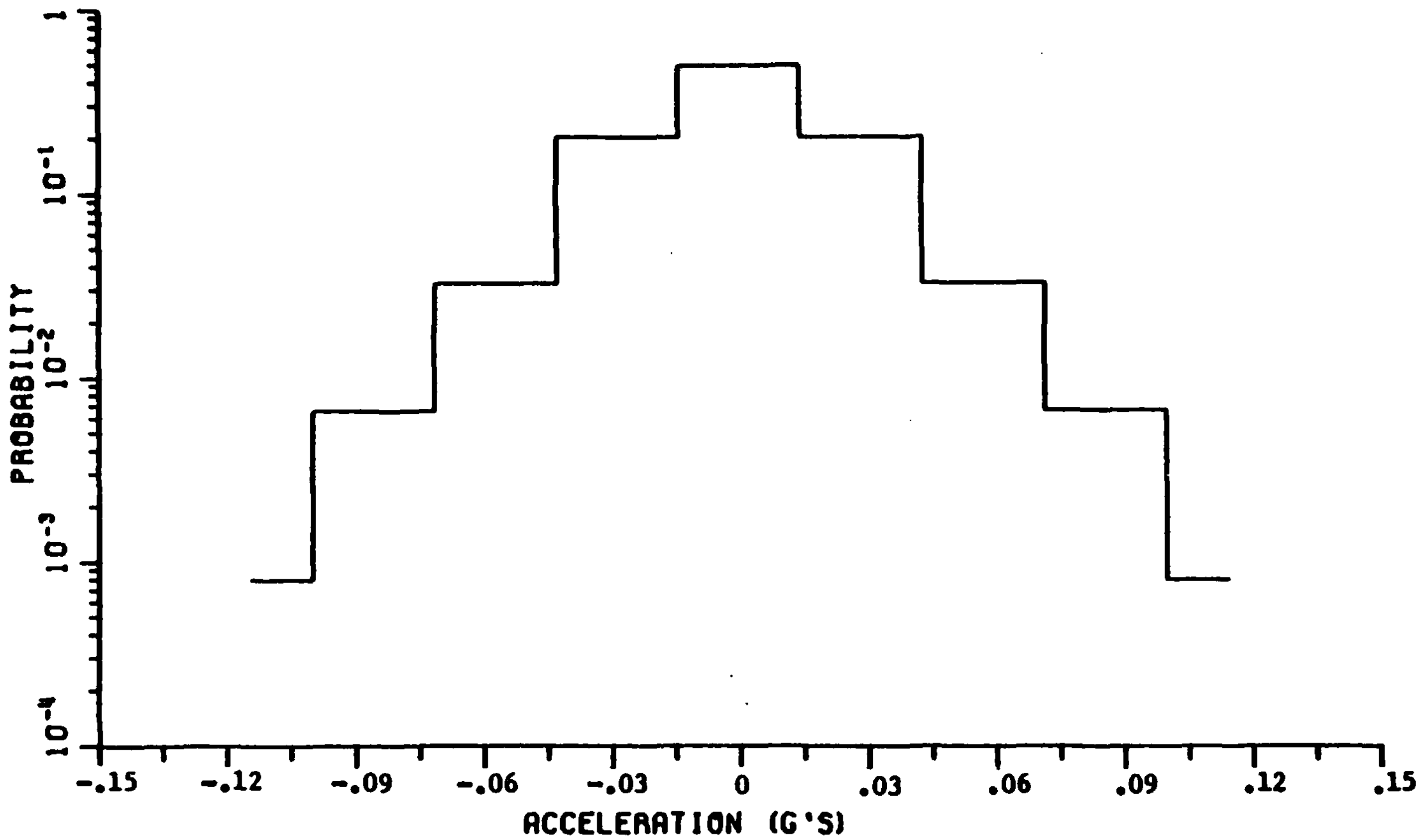


FIGURE 2-4
AVERAGE RELATIVE CROSSTRACK ACCELERATION HISTOGRAM

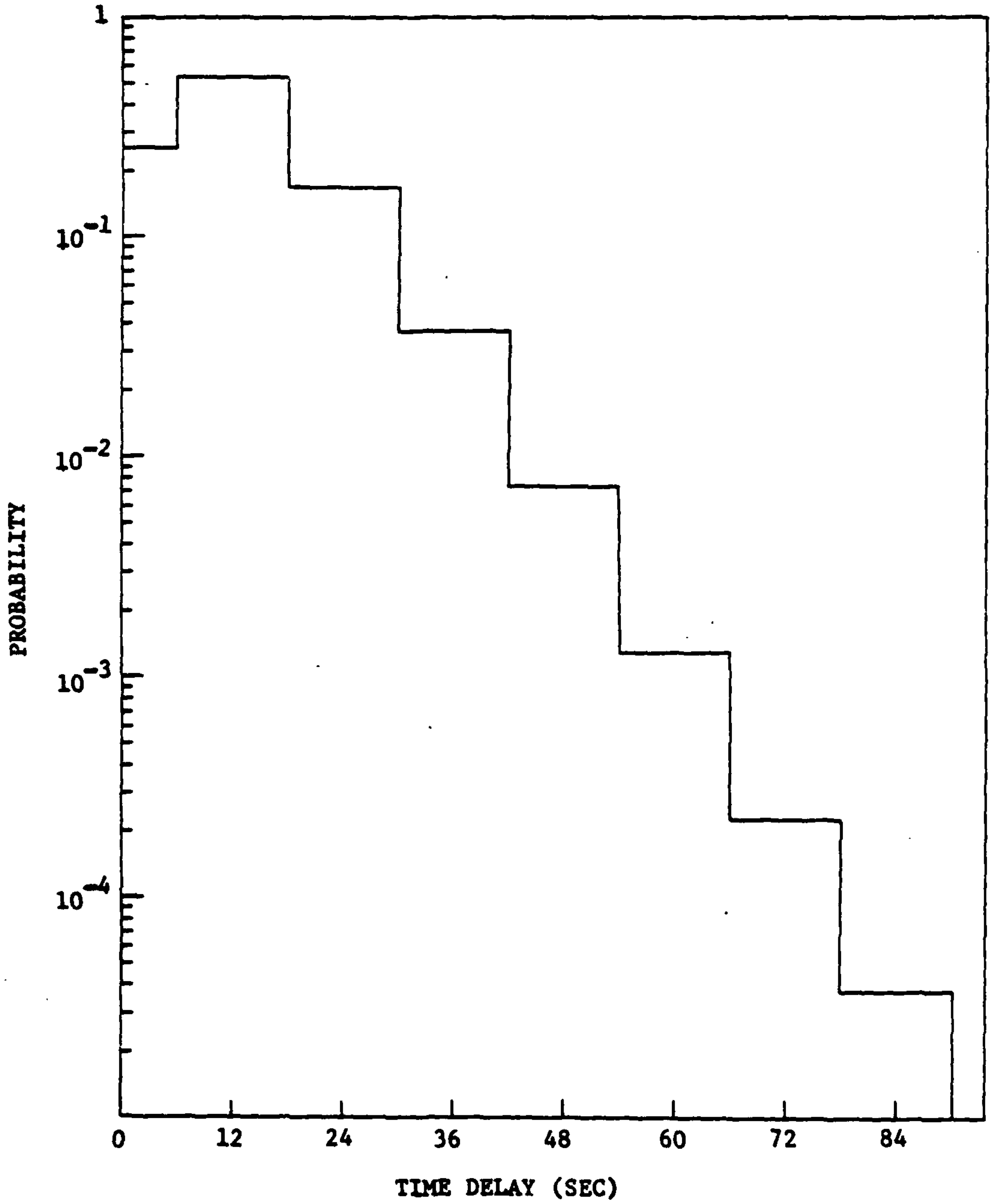


FIGURE 2-5
REACTION/COMMUNICATION TIME DELAY HISTOGRAM

simulation. This simulation is described in Appendix B of this report.[8] The resulting parameters of the surveillance/tracker system error distribution for opposite direction flows are given in Table 2-1.

After the conflict is detected and one of the pilots is informed, the notified aircraft is assumed to make a horizontal turn. The rate of turn that the pilot makes is assumed to be randomly chosen from one of the distribution of turn rates shown in Figure 2-6. These turn rate distributions are equivalent to randomly choosing a bank angle between 10 and 30 degrees and between 25 and 30 degrees. Appendix B of Volume II of Reference 7 gives the details of the derivation of this distribution.

These sets of data will be used in the estimation of the probability of horizontal overlap. The following sections will discuss the estimation procedure.

2.3.2 The Conflict Surface

Two aircraft flying in opposite directions on parallel adjacent route segments will pass at some point in time. Prior to the passing there is is a possibility that the pair of aircraft will receive a Conflict Alert. Given that the aircraft are involved in a conflict alert, it is important to know the geometry (i.e. separations and closing speeds in each dimension) which generated the alert because some geometries are more easily resolved than others. The conflicts that are not resolved are of interest because they represent the situations where the aircraft horizontally overlap each other.

In the opposite direction scenario the conflict geometry is defined by six parameters:

1) the alongtrack separation, x,
2) the crosstrack separation, y,
3) the crosstrack closing speed, $\dot{y}$,
4) the crosstrack speed of aircraft 1, $\dot{y}_1$,
5) the forward speed of aircraft 1, S_1, and
6) the forward speed of aircraft 2, S_2.

When an aircraft pair has a set of parameter values such that the aircraft are projected by the ATC automation to be 5 nmi apart within 2 minutes, the aircraft pair is said to be on the conflict surface. By fixing three of the parameters, the

TABLE 2-1
SURVEILLANCE/TRACKER INPUT PARAMETERS

INPUT	VALUE
Alongtrack Separation Error (x)	0.3 kts
Crosstrack Separation Error (y)	0.3 kts
Crosstrack Closing Speed Error ($\dot{y}$)	39 kts
Crosstrack Speed of Aircraft 1 Error ($\dot{y}_1$)	23 kts
Correlation Coefficients	
ρ_{xy}	0.0
$\rho_{x\dot{y}}$	0.0
$\rho_{x\dot{y}_1}$	0.0
$\rho_{y\dot{y}}$	-0.6
$\rho_{y\dot{y}_1}$	-0.4
$\rho_{\dot{y}\dot{y}_1}$	+0.5

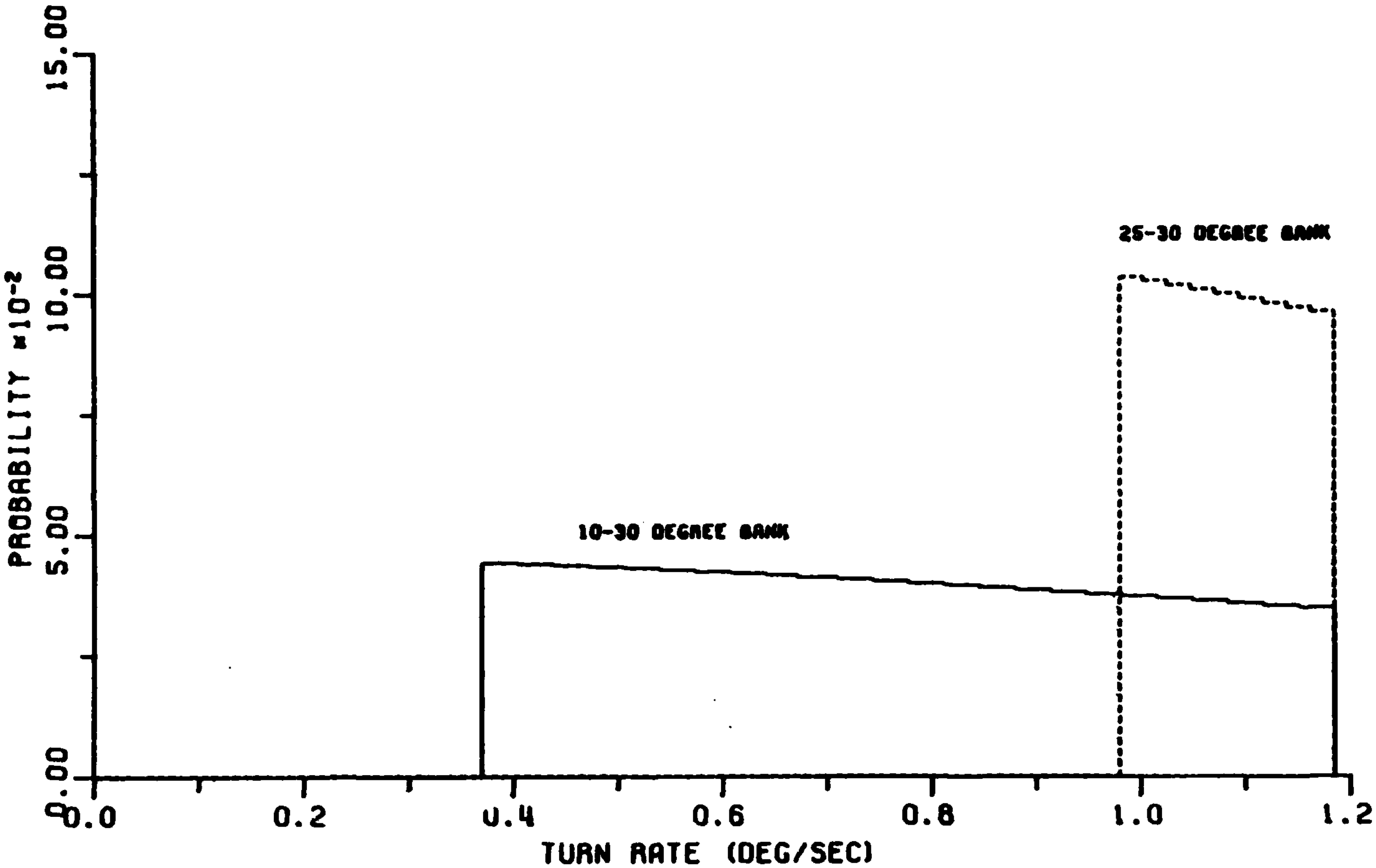


FIGURE 2-6
TURN RATE HISTOGRAM

conflict surface in terms of the other three parameters can be drawn as in Figure 2-7. The sign conventions and the development of this surface are discussed in Appendix C of this report.[8]

There are two distinct regions of the conflict surface. At large values of x the surface tends to drop off steeply in the y dimension. This region is called the leading edge and it encompasses those geometries where the aircraft are projected to be 5 nmi apart in exactly 2 minutes. The rest of the conflict surface has a more gentle slope and is called the backside region. This region encompasses those geometries where the aircraft are projected to be 5 nmi apart in less than 2 minutes.

The trajectory of an opposite direction aircraft pair in Figure 2-7 would start at a large value of x (about 35 nmi) and fly in the decreasing x direction until $x = 0$ where the pair would pass. Nominally, the y separation would be the route spacing if the aircraft were on their respective route centerlines. The $\dot{y}$ value would depend on the crosstrack velocities of the two aircraft. The $\dot{y}$ values will also influence subsequent values of y along the trajectory. If the aircraft pair starts at $x = 35$ nmi and flies to $x = 0$ without its trajectory touching the conflict surface then that aircraft pair will not receive a conflict alert. If, on the other hand, the trajectory penetrates the conflict surface the pair will receive a conflict alert.

The concept of penetrating the conflict surface is incorporated into the analysis by considering the vertical plane at $x = 35$ nmi. All the aircraft pairs have to pass through this plane. The plane is also located at a large enough value of x that there is no possibility of a conflict alert at that value of x. The plane at $x = 35$ nmi is divided into numerous cells which represent the feasible range of crosstrack separations and velocities of the aircraft pair. Given the values of the separation and velocities at the center of a cell, a trajectory can be constructed. Either the trajectory will penetrate the conflict surface or it won't. If it does penetrate the conflict surface the mapping from the plane to the conflict surface is noted. Associated with this mapping is an estimate of the probability that the aircraft pair passed through the plane at $x = 35$ nmi with the specific separations, velocities, and accelerations. This probability estimate is based on the joint histogram of separation and closing speeds and the histogram of average relative accelerations. The probability also depends on

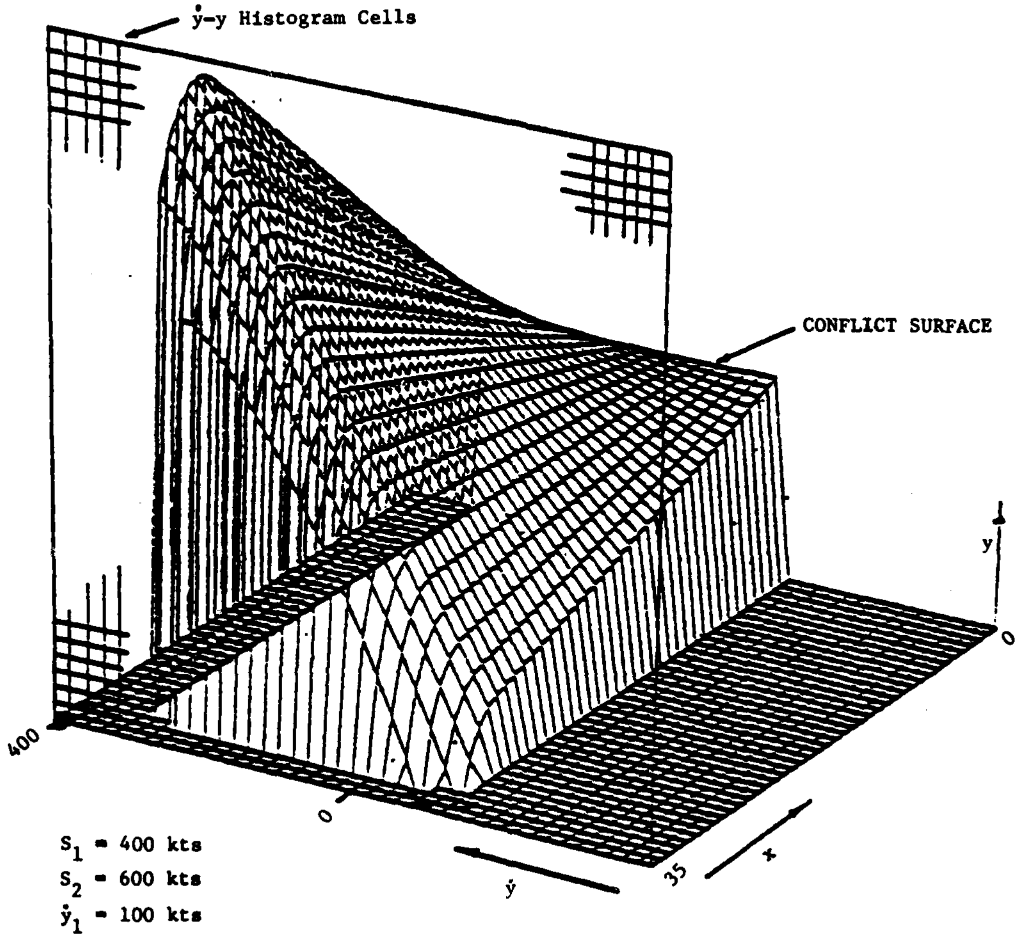


FIGURE 2-7
CONFLICT SURFACE

the route spacing.

2.3.3 Delay Modelling

The trajectories that were discussed in the previous section are considered to be the actual trajectories of the aircraft pairs. The apparent trajectories are the trajectories that the system would see because of errors introduced by the surveillance system and the tracker. This means that when the actual trajectory penetrates the conflict surface it may not appear to the system that the aircraft pair is on the conflict surface. It is assumed that delays in detecting a conflict may be incurred because of this difference between the actual trajectory and the apparent trajectory. (The surveillance/tracker errors could also induce early detections or false alarms, but these cases are being ignored to be conservative in the estimate of the probability of overlap.) The detection delay is characterized as a distribution of delay times. Appendix D of this report(8) describes a simulation which was run to determine the detection delay distribution. It was found that there were two distinct delay distributions. One characterized the trajectories that penetrated the conflict surface at the larger values of x (the "leading edge" of the surface in Figure 2-7). The other detection delay distribution characterized the trajectories that penetrated the conflict surface at the smaller values of x (the "backside" of the surface in Figure 2-7). Estimates of these two distributions are given in Figure 2-8.

The detection delay is not the only delay considered in this analysis. The reaction/communication delay is also considered. The source of this delay was cited in the section on data and the distribution that is used in the analysis was shown in Figure 2-5. To arrive at the total delay distribution, the reaction/communication delay distribution is convolved with each of the detection delay distributions. The technique that was used to convolve the distributions was the Fast Fourier Transform technique described in Appendix D of Volume II of Reference 7. The resulting total delay distributions are shown in Figure 2-9.

2.3.4 Resolution Modelling

Once the aircraft pair has crossed through the conflict surface, has been detected, and one pilot has been informed of the event, the resolution maneuver is initiated. As in the same direction

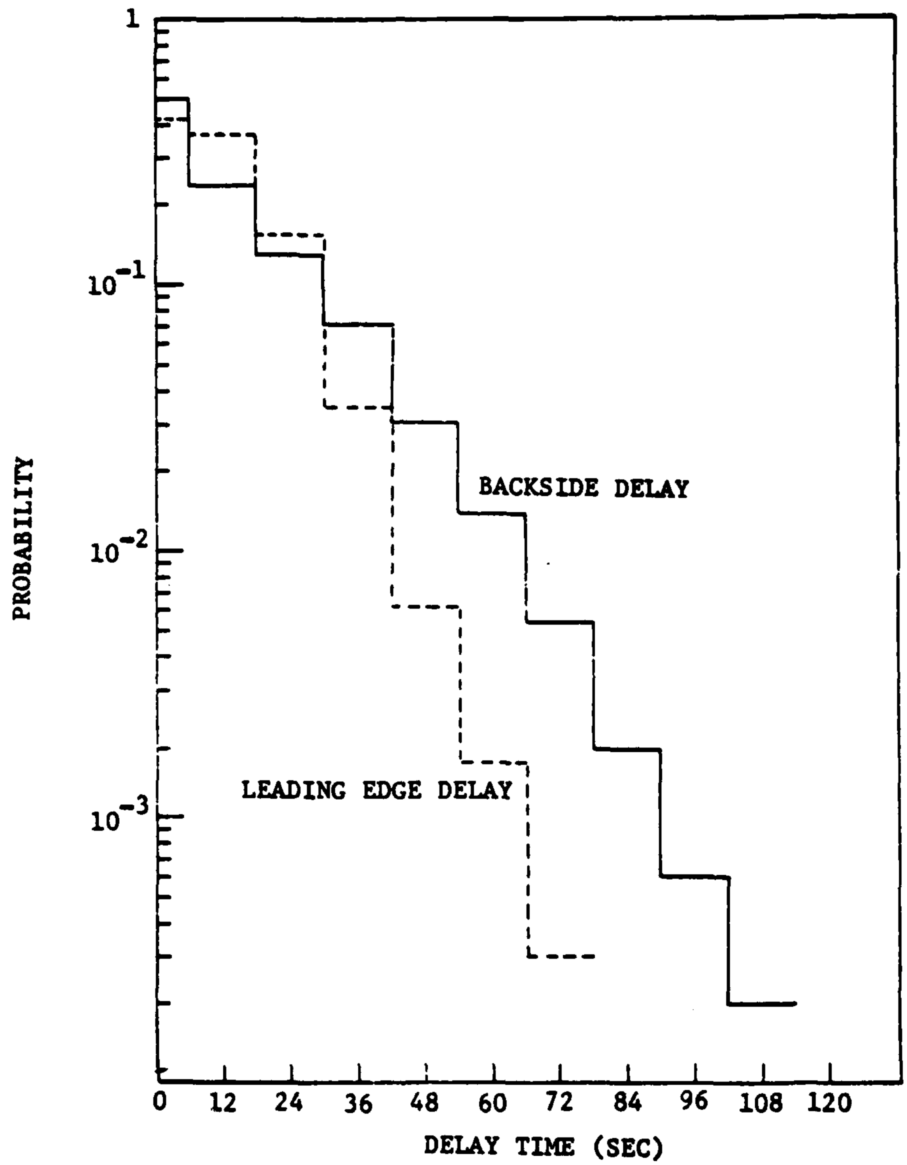


FIGURE 2-8
DETECTION DELAY TIME HISTOGRAM

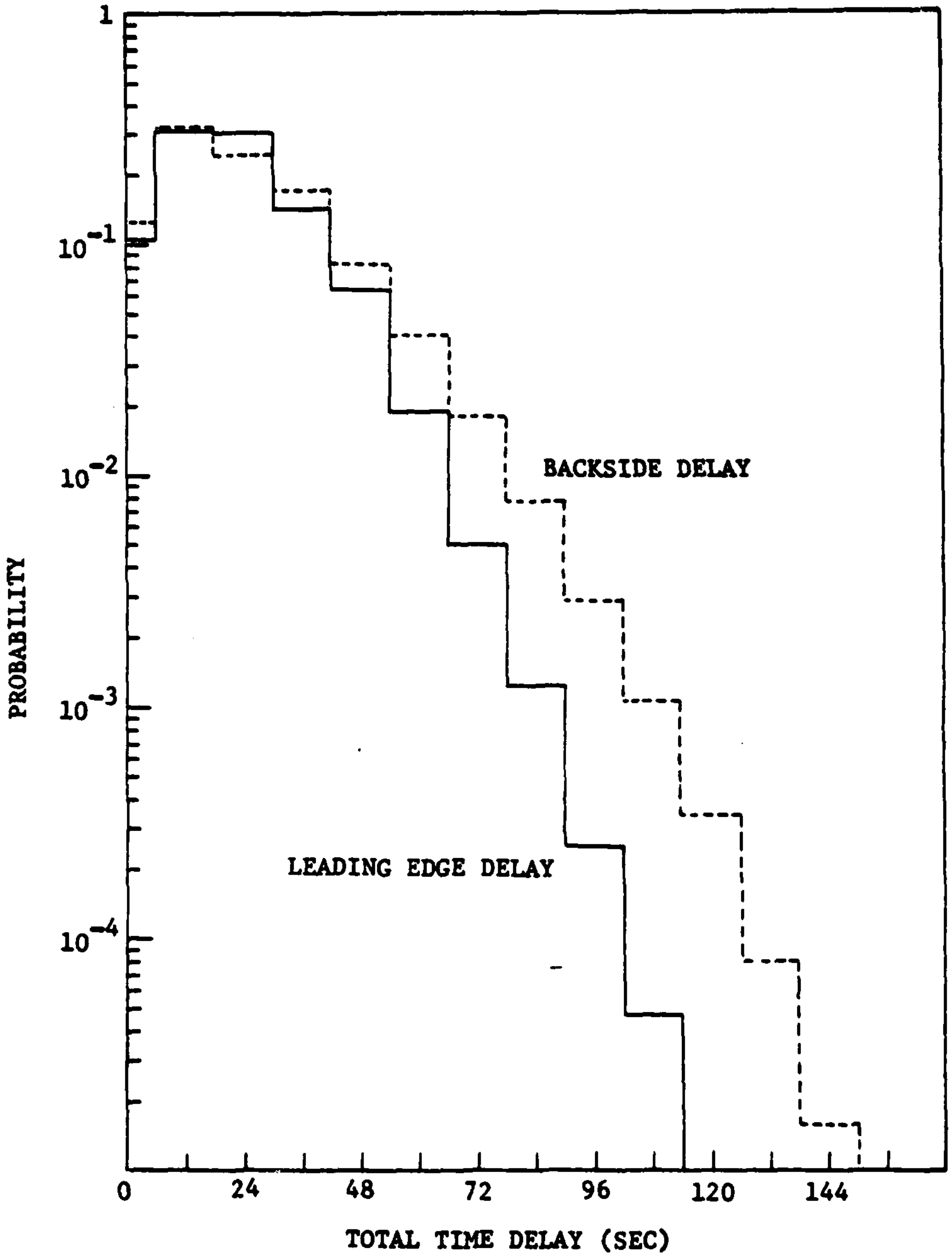


FIGURE 2-9
TOTAL TIME DELAY HISTOGRAM

analysis the resolution is assumed to be a horizontal coordinated turn made by only one of the aircraft. The difference between the same direction analysis and the opposite direction analysis is that in the opposite direction scenario the resolution maneuver need not be back toward the assigned route centerline. This section will discuss the direction in which the maneuvering aircraft is told to turn, the chances that this not the better choice and the conditions under which such a turn will lead to an overlap condition.

2.3.4.1 Turn Sense

The direction in which the maneuvering aircraft will be commanded to turn in this analysis will be based on a Conflict Resolution Advisory algorithm currently under development for the National Airspace System (NAS).[9] This Conflict Resolution algorithm will complement the Conflict Alert function in NAS to give the controller a set of alternative resolution maneuvers. Appendix E of this report[8] presents the details of the Conflict Resolution algorithm applicable to the geometries being considered in this analysis.

The direction an aircraft is told to turn is selected by the Conflict Resolution algorithm on the basis of a "prohibited wedge" of headings for the turning aircraft. If the aircraft's heading is within the "prohibited wedge" as shown in Figure 2-10, the aircraft will turn in the direction which will minimize the change in heading necessary to get out of the prohibited wedge. In the example shown in Figure 2-10 the aircraft would turn to the right.

2.3.4.2 Probability of Improper Turn Sense

The command by the controller to the pilot to make a left or a right turn is based on the algorithm discussed in the previous section. If the surveillance system were perfect that algorithm would give the proper turn direction. However, the surveillance system and the tracker do introduce errors so that there is a probability that the turn direction selected by the Conflict Resolution algorithm is the wrong direction.

Of course, it must be recognized that this suggested turn is purely advisory in nature and the controller may take other actions he considers to be more effective, particularly if the conflict is perceived to be severe. Thus restricting the resolution maneuvers to that selected by Conflict Resolution is

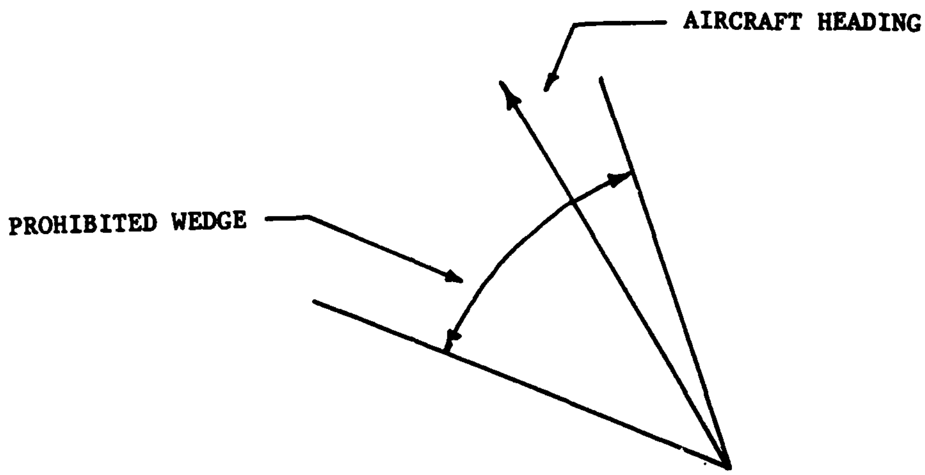


FIGURE 2-10
PROHIBITED HEADINGS

another source of conservatism in the analysis.

It was found that if the aircraft heading were near the middle of the prohibited wedge of headings (see Figure 2-10) the chances are 50-50 that the improper turn sense would be selected by Conflict Resolution. If the aircraft's heading were near the edge of the prohibited wedge of headings the chances are remote that the surveillance errors would cause an improper turn sense. A simulation was performed to arrive at an estimate of the probability of the Conflict Resolution algorithm selecting the proper turn sense as a function of the position of the aircraft heading within the wedge of prohibited headings. This simulation is discussed in Appendix E of this report.[8] The results of that simulation are shown in Figure 2-11. The abscissa axis is the ratio of the minimum angle between the aircraft heading and the edge of the prohibited wedge to the total angle covered by the prohibited wedge.

2.3.4.3 Overlap Region

The opposite direction conflict monitoring analysis ultimately needs to estimate the probability of horizontal overlap. Therefore, given a five-dimensional cell on the conflict surface (crosstrack separation, crosstrack closing speed, alongtrack separation, crosstrack speed of one aircraft, and the relative lateral acceleration) it is necessary to be able to describe the circumstances under which the aircraft pair will overlap horizontally. After the aircraft pair penetrates the conflict surface there are the delays discussed above. These delays are followed by a turn to the right or left with a probability dependent on the conflict geometry and the surveillance/tracker errors. Then, depending on the rate of turn which the pilot chooses to make, the aircraft pair will either overlap or it won't.

The analysis samples over the conflict surface cell in all five dimensions. At each sample point it is possible to determine the regions of delay time, turn rate, and turn direction which will result in an overlap condition. The details of this determination can be found in Appendix F of this report.[8] The composite overlap region for the cell forms a very distinctive pattern as shown in Figure 2-12. This figure shows a cluster of points of turn rate versus delay time. A positive turn rate indicates a left turn. One can draw an envelope (shown as asterisks in Figure 2-12) which demarcates the cluster of points. Thus, any time delay - turn rate combination above the envelope shown in Figure 2-12 would be said to result in an

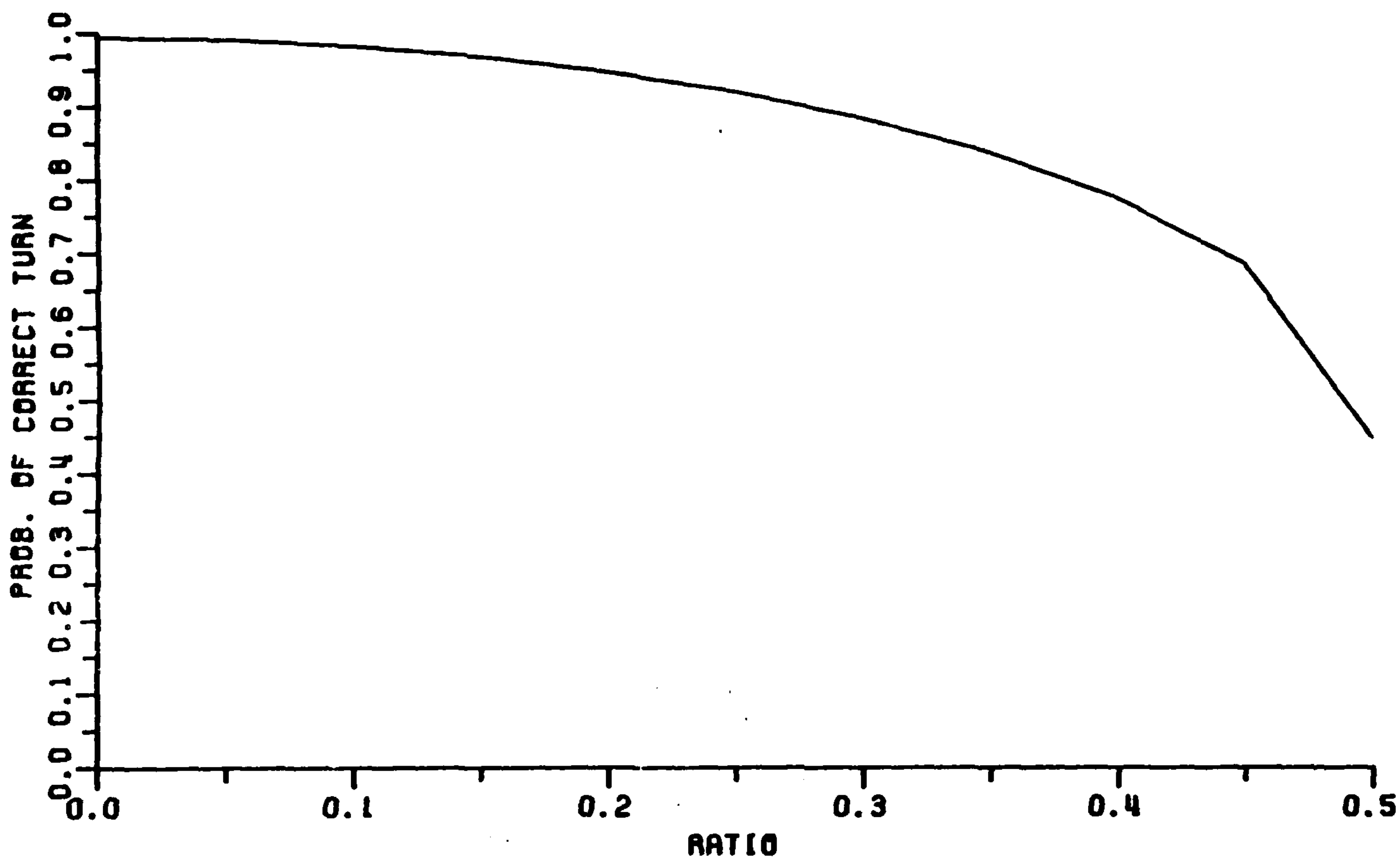


FIGURE 2-11
PROPER TURN SENSE PROBABILITY

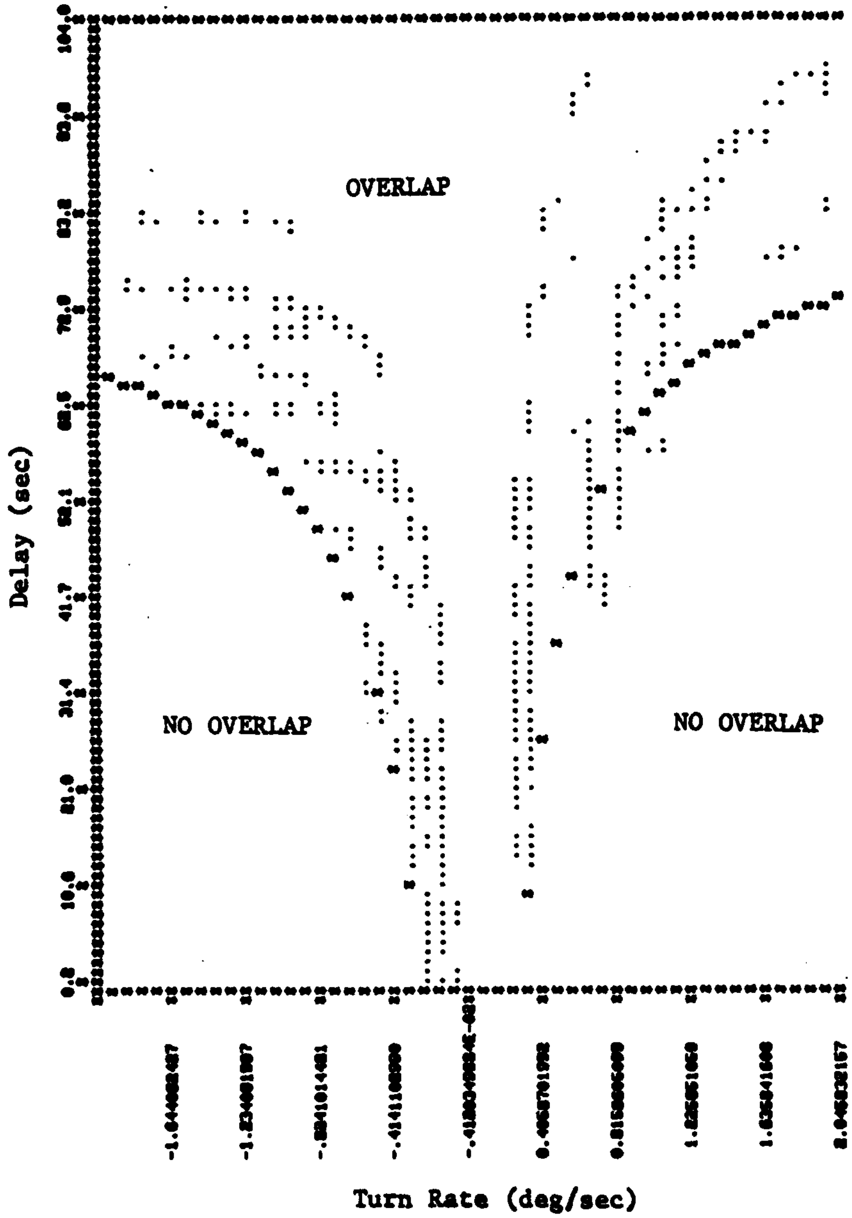


FIGURE 2-12
HORIZONTAL OVERLAP REGION

overlap of the aircraft pair. In this conflict surface cell there are both right and left turns that could result in overlap. This means that this cell's basic conflict geometry is that of a head-on encounter. For most conflict surface cells one would only see positive or negative turn rates and not both.

2.3.5 Probability of Horizontal Overlap

The previous sections have addressed the components that are used to estimate the probability of horizontal overlap. This section will show how these components are used to estimate the probability of horizontal overlap. The entire estimation process can be summarized in the following equation:

$$P_H = P_{2R} \sum_{ij} P(\text{overlap} \mid CS_j) * P(CS_j \mid y_i, \dot{y}_i, \dot{y}_{1i}, \ddot{y}_i) * P(y_i, \dot{y}_i, \dot{y}_{1i}, \ddot{y}_i) \qquad (2\text{-}1)$$

The terms in this equation will be explained starting from left to right. P_{2R} is the probability that the aircraft pair is within an aircraft length (2R) of the plane at x=35 nmi. The value of this quantity will depend on the flow rates on each route. The computation of this number is discussed in Appendix E of Volume II of Reference 7.

The term $P(\text{overlap} \mid CS_j)$ is the probability of getting into overlap given that the aircraft pair started in conflict surface cell j. The computation steps necessary to estimate this probability are given in Appendix G of this report.[8]

The term $P(CS_j \mid y_i, \dot{y}_i, \dot{y}_{1i}, \ddot{y}_i)$ is the probability of the trajectory of the aircraft pair penetrating conflict surface cell j given that the trajectory passed through cell i on the plane at x=35 nmi. Cell i is characterized by the crosstrack separation (y_i), the crosstrack closing speed ($\dot{y}_i$), the crosstrack speed of one of the aircraft ($\dot{y}_{1i}$), and the relative crosstrack acceleration ($\ddot{y}_i$). In this analysis this probability is either one or zero. Either the trajectory penetrates the conflict surface at a particular cell or the trajectory does not penetrate the conflict surface at all.

The term $P(y_i, \dot{y}_i, \dot{y}_{1i}, \ddot{y}_i)$ is the probability that the trajectory passed through cell i on the plane at x=35 nmi. The estimate of this probability is based on the histogram data of crosstrack deviation and crosstrack speed and the simulation of average relative crosstrack accelerations (Appendix A[8]).

Results of using trial data in expression (2-1) for the probability of horizontal overlap are given in Section 4.

3. INTERVENTION RATE ANALYSIS

The rate at which a controller must intervene with a pair of aircraft due to a Conflict Alert is a controller workload factor. For several reasons the intervention rate must be low for the system to be effective. First, it would be difficult for the controller to perform all of his tasks if he had to respond to alerts very often. Second, if there were many alerts and the controllers issued commands to the pilots due to these alerts, the controllers would be assuming some of the pilot's navigation function. It is therefore desirable to minimize the controller intervention rate due to Conflict Alerts.

The approach used to estimate the controller intervention rate is a simulation using observed aircraft flight data, simulated entry times, and the NAS Conflict Alert function.

3.1 The Simulation Approach

In order to model the NAS Conflict Alert function a simulation was performed. A flow chart of the simulation is shown in Figure 3-1. The simulation used smoothed radar tracks of aircraft observed during the data collection and simulated their entry times and flight along a pair of opposite direction parallel routes. The routes were approximately 130 nmi long which equals about 20 minutes flying time. The aircraft tracks were those of actual aircraft which were observed in the FAA's navigation data collection. The times of entry of aircraft on their respective routes were chosen based on the desired flow rates on the routes. The addition of the entry times to the track data defines the traffic flow in the simulation.

Since the tracks from the FAA's data collection were smoothed to remove the radar errors, radar errors had to be added to the track data during the simulation. This was accomplished by choosing a radar site relative to the routes and adding range and azimuth errors to each aircraft position report. The errors that were used were representative of the radar beacon system. The range error was 240 feet (1 sigma) and the azimuth error was 0.26 degrees (3 ACPs) (1 sigma). The errors were assumed to be normally distributed with zero mean.

At each radar update time (every 12 seconds), a set of radar returns from every aircraft currently on the routes was processed. This processing included tracking the returns through an emulation of the NAS tracker, and then using the tracker position and velocity estimates in the Conflict Alert

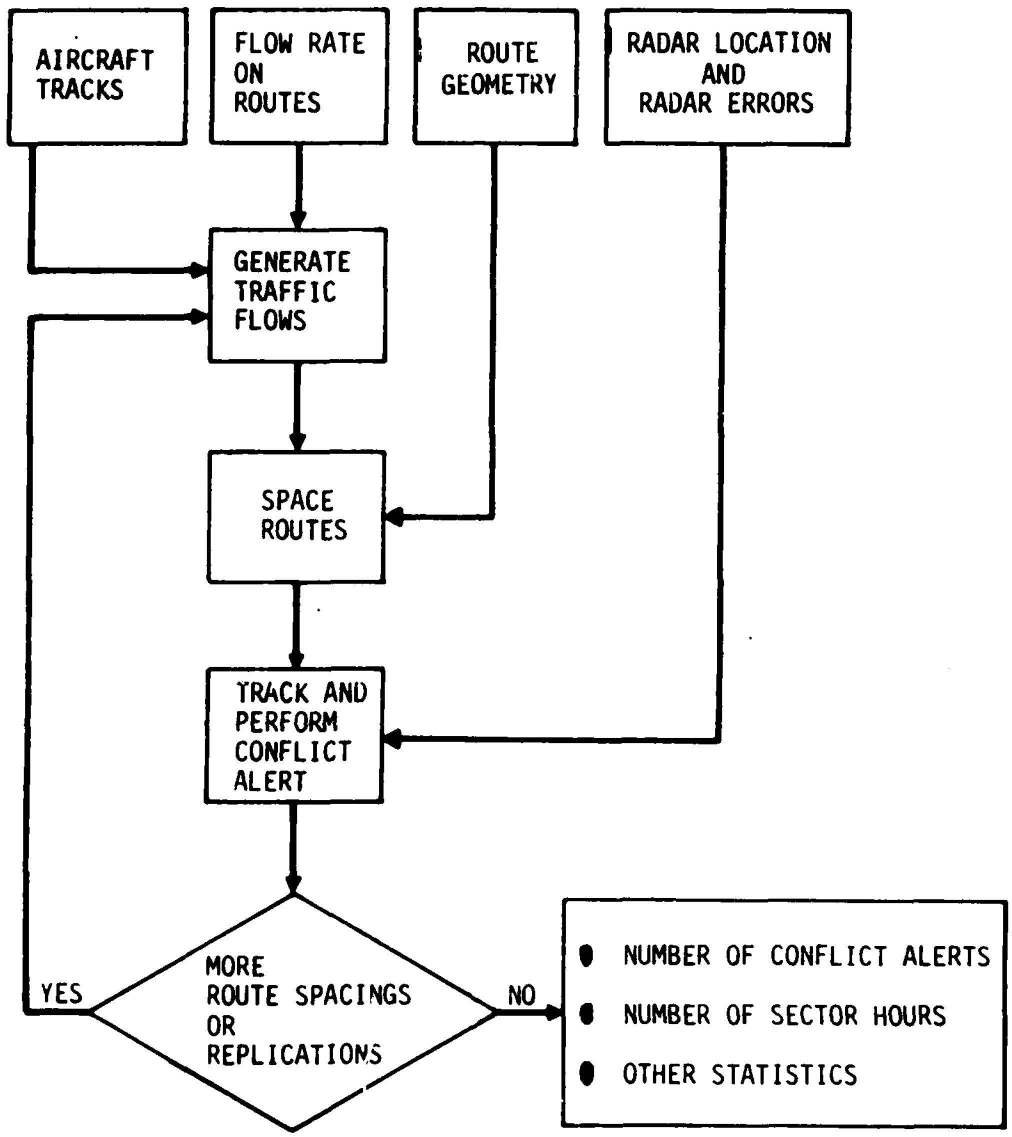


FIGURE 3-1
INTERVENTION RATE SIMULATION

This will affect both the pair's closing speed and its separation. If enough pairs receive such alerts, then the joint distribution of crosstrack separation and closing speeds would be changed also.

function.

The Conflict Alert function in the simulation considers only the horizontal plane in determining conflicts. This is in contrast to the NAS Conflict Alert which also considers aircraft transitioning in the vertical plane. In the horizontal plane, the simulation uses the same decision criteria as the NAS Conflict Alert in determining whether a pair of aircraft generate an alert. This includes the two-out-of-three detection logic by which a Conflict Alert is declared only if the pair of aircraft are detected in potential conflict on two out of the last three successive filter passes.

When an aircraft pair receives an alert in the simulation, that pair is no longer considered for additional alerts. Furthermore, no attempt is made to realign the tracks of alerted aircraft to account for any response to controller interventions. This means that a given aircraft pair can be detected in conflict only once in the sector of interest. However, the fact that a particular aircraft received an alert with one aircraft does not preclude it from receiving alerts involving other aircraft.

The output from the simulation consists of several statistics. For the controller intervention rate the statistic of interest is the number of Conflict Alerts per sector hour. Other statistics include the number of hours the simulation was run (sector hours), the number of flying hours in the sector, the number of aircraft generating those flying hours, the maximum instantaneous aircraft count, and the number of Conflict Alerts declared.

A more detailed description of the simulation is provided in Appendix G of Volume II of Reference 7.

3.2 Limits Imposed On the Horizontal Overlap Analysis by the Intervention Rate

The assumption is made in the horizontal overlap analysis that the joint crosstrack separation, crosstrack closing speed histogram represents time-invariant flying errors. This assumption certainly breaks down if many aircraft pairs get alerts. It is obvious that as an aircraft pair receives an alert, at least one of the aircraft will change its heading.

4. TRIAL RESULTS

These trial results are produced in order to allow an evaluation of the applicability of the procedural and conflict monitoring collision risk analyses being performed under the VOR-defined air route separation program. The results in this section are preliminary. There are several issues which need to be resolved before confidence in the analysis and the use of the results can be justified. These issues will be discussed in the recommendations section.

Section 4.1 will address the results from the probability of horizontal overlap analysis. The parameter choices and data which were entered into the analysis are identified in Section 4.1.1 The results from both the conflict monitoring and the procedural analyses are presented in Section 4.1.2. This is followed by the results from the intervention rate analysis in Section 4.2.

4.1 Horizontal Overlap Analysis Results

4.1.1 Inputs

The parameters and data that drive the conflict monitoring horizontal overlap analysis are listed in Tables 4-1 and 2-1. Where data are used the data were from observed flights in the Cleveland ARTCC. This is to provide consistency with the same direction analysis in Reference 7. In most other cases the input is either derived from data or a value was chosen which was based on ancillary simulations or judgment. The choice of parameters such as the aircraft size and velocity, and the characteristics of the delay and bank angle distributions used here may differ from the values eventually selected by the FAA to be representative of the system in general. However, in almost all cases the same values were chosen for this opposite direction analysis as were chosen for the same direction analysis in Reference 7. The differences can be found in the aircraft velocities, the bank angle distribution, and the parameters that characterize the surveillance/tracker system. The following discussion will highlight the inputs and their values.

TABLE 4-1
INPUT TO PROBABILITY OF HORIZONTAL OVERLAP ANALYSIS

INPUT	VALUE
Crosstrack Deviations and Speed	-
Average Relative Crosstrack Accelerations	-
Look-Ahead Time	2 min
Minimal Allowable Radar Separation	5 nmi
Radar Update Rate	1 per 12 sec
Aircraft Size	R = 0.0126 nmi λ_x = 153 feet λ_y = 108 feet λ_z = 34 feet
Aircraft Velocity	390,520 kts
Delay Distribution	Gamma C=2 B=6.17
Bank Angle Distribution	Uniform 10-30 degs 25-30 degs
Route Spacing	8,10,12,14,16 nmi

The crosstrack deviation and crosstrack velocity come directly from the data that was collected during the VOR-defined air route separation program. The form of this data is a joint histogram of the crosstrack deviations and crosstrack speeds for single aircraft. This histogram is convolved with itself as described in Appendix F of Volume II of Reference 7 to arrive at a joint histogram of crosstrack separation and crosstrack closing speeds. The joint histogram which was used here was based on aircraft at a distance of 50 nmi from the VORs in the Cleveland ARTCC. The procedural analysis uses the marginal distribution of the crosstrack separation.

The average relative crosstrack acceleration histogram was derived via simulation as discussed in Appendix A of this report.[8] Although accelerations are thought to be important in modelling the opposite direction encounters, the modelling effort is not for enough along at this point to include the results from accelerated encounters.

The look-ahead time and minimum allowable radar separation are two parameters of the Conflict Alert function. Even though the NAS Conflict Alert has more parameters (as discussed in the following section on the intervention rate model), the essence of the conflict detection logic is embodied in these two. The nominal values for these parameters are 2 minutes for the look-ahead time and 5 nmi for minimum allowable radar separation.

The radar parameters include the update rate and the radar/tracker errors in position and velocity. The radar update rate for the current en route radars is once every 10 or 12 seconds. A 12 second scan time was chosen for use in this analysis. The radar is characterized as having a range quantization error of 0.125 nmi, and azimuth error of 3 ACP's (1 sigma) and a detection probability of 0.95.

The aircraft size used in this analysis is representative of a Boeing model 727-200. This aircraft was the one observed most often in the Cleveland Center. The aircraft size is given in two ways in Table 4-1. One way is the radius of the right cylindrical collision shape used to compute the probability of horizontal overlap in the surveillance environment. The other way is the width and length of the rectangular collision shape used in the analysis of the probability of horizontal overlap in the procedural environment.

The average aircraft velocities listed in Table 4-1 are the

average ground speed of the westbound (390 knots) and the eastbound (520 knots) flights on the routes of interest in the Cleveland ARTCC. There was a spread of observed velocities which depended on both the aircraft type and the winds. However, the average velocity is used in the analysis.

The delay and bank angle distributions provide the characterization of the collision avoidance maneuver. The delay distribution is based on a British simulation where controllers monitored a threshold line at a given distance from the route centerline [10]. The controllers had computer assistance in determining aircraft transgressions of the threshold line and the delay represented the reaction time for the controllers to send the message to the pilot but did not include the pilot's response time. The delay time data from this simulation was fit to a special form of a Gamma function. The parameters of this distribution imply a mean delay time of about 12 seconds. However, the form of the distribution allows for very long (and low probability) delays. Delays greater than 1 minute are assumed to occur about 0.06% of the time.

Two bank angle distributions were assumed to be uniform with ranges from 10 to 30 degrees and from 25 to 30 degrees. The maximum value of the bank angle was set at 30 degrees (corresponding to a 0.5g turn) because of passenger comfort considerations. The turn rate will then depend on the velocity of the aircraft. The lower limit on the bank angle was chosen to be 10 or 25 degrees. The 10 degrees value corresponds with that used in the same direction analysis. Because of the higher closing rates associated with conflicts arising from opposite direction traffic flows, it was felt that a higher turn rate would likely be used for conflict resolution.

The route spacings which were examined are in the range of 8 to 16 nmi The upper end of this range was chosen because the trial data were taken on routes that are spaced about 16 nmi apart. The lower end of the range was chosen because the current VOR route establishment criteria allows routes to be spaced as close as 8 nmi.

The radar/tracker errors were arrived at through the simulation described in Appendix B of this report.[8] This simulation used as an input the radar range and azimuth errors and the probability of detecting a return on a given scan. The radar beacon errors listed in Table 4-1 are the values used as design parameters for the current system. The output of the simulation was a distribution of position and velocity errors. The

distribution is assumed to be a quadrivariate normal distribution with the parameters listed in Table 2-1.

There is an element of conservatism placed in the analysis at this point. The radar/track position and velocity errors are assumed to have a quadrivariate normal distribution with zero mean with the standard deviations and correlation coefficients as determined from the simulation. This assumption is conservative because the normal distribution has heavier tails than the simulated errors. This means that the normal distribution will indicate that the aircraft pair is more likely to be observed outside the conflict region when it is really within the conflict region. This will lengthen the detection process as modelled and hence yield probability of horizontal overlap estimates that are higher than those that would result from the direct use of simulated errors.

4.1.2 Results

Estimates of the opposite direction flow rates that could be supported on a pair of parallel routes at a range of spacings is shown in Figure 4-1. For the purposes of illustration, a flow rate can be supported if the probability of horizontal overlap is below that required to be consistent with the safety level deemed to be minimally acceptable in a number of recent U.S. studies including the establishment of the Central East Pacific route system [11] and the revised ground obstruction clearance requirements [12].

The measure shown for opposite direction flow is the probability of longitudinal overlap, P_x. The P_x term reflects the number of opposite direction passings resulting from non-cardinal altitude usage on adjacent routes. As a point of reference, the opposite direction flows observed in Cleveland ARTCC resulted in a P_x of 5.1×10^{-6}. This value indicates that non-cardinal altitudes were very infrequently used when there was an appreciable flow of traffic in the opposite direction on the adjacent route.

The trial results shown on Figure 4-1 indicate that route spacings of 15 nautical miles or more are required to support the opposite direction flows observed in Cleveland without surveillance. For the conflict monitoring environment several situations are shown based on varying assumptions about the resolution procedure. Cases are shown where the maneuvering aircraft is assumed to turn with 10 to 30 degree bank angle or a

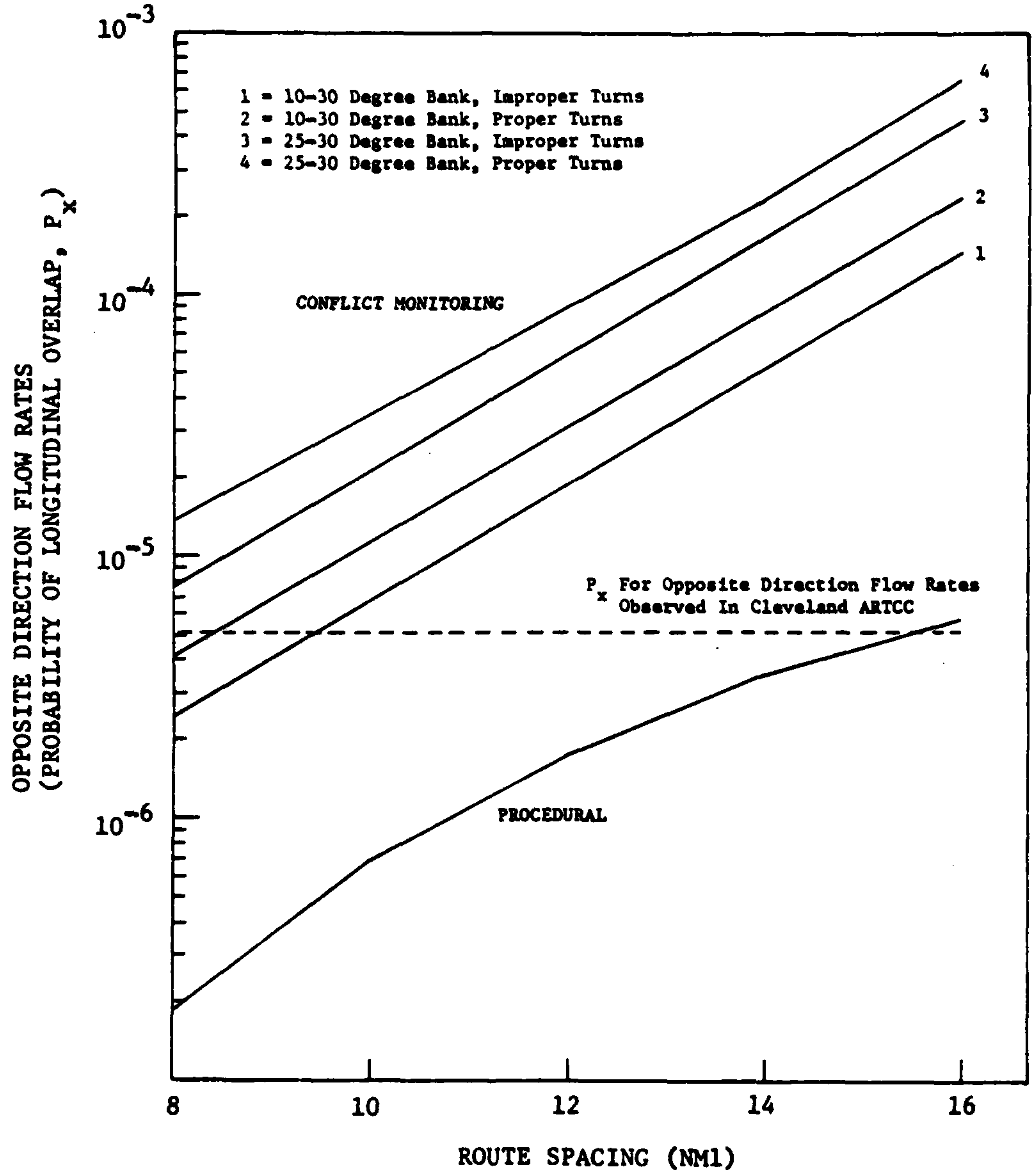


FIGURE 4-1
SUPPORTABLE OPPOSITE DIRECTION FLOWS

25 to 30 degree bank angle and whether or not the sense of the selected turn permits conflict resolution with the minimum heading change (i.e. whether a "proper" turn was always selected). With proper and expeditious turns assumed (case 4 of Figure 4-1), higher flow rates can be supported in a conflict monitoring environment. It should be noted that routes spaced at 8 nmi or greater can support the opposite direction flow observed in Cleveland ARTCC.

In evaluating these results one should remember that they are preliminary. The data is representative of only one distance from the VOR (50 nmi) on only a limited number of routes in one ARTCC. Conflicts involving turning aircraft (accelerated flight) have not been included in these results. Such conflicts, to be addressed in subsequent work, need to be included in the analysis before a final assessment of the effectiveness of conflict monitoring can be made.

4.2 Intervention Rate Analysis Results

4.2.1 Inputs

The route structure and sector boundaries used in the conflict monitoring intervention rate simulation are shown in Figure 4-2. The basic data which drive the simulation is a set of aircraft tracks from about 200 aircraft. These data are the smoothed radar tracks consisting of an estimated position for each radar scan. The tracks are a random sample from the two adjacent opposite direction routes (J60 and J146) in the Cleveland ARTCC over the entire data collection period. Only those aircraft which flew the entire route segments of interest without controller intervention were eligible to be included in the sample.

In the simulation these aircraft were assigned to the same parallel routes that they flew in the Cleveland ARTCC. The starting points and orientation of the routes are given in Figure 4-2. The Conflict Alert function in the simulation only operates when the aircraft are in the sector of interest. The sector boundaries are also given in Figure 4-2. All the coordinates are given with respect to an arbitrary ARTCC rectangular coordinate system. The position of the radar was chosen to coincide with the Pittsburgh radar. The radar errors and update rate are the same that were used in the horizontal overlap analysis. The simulation duration was chosen to be 4 hours. This includes the starting and ending time for the

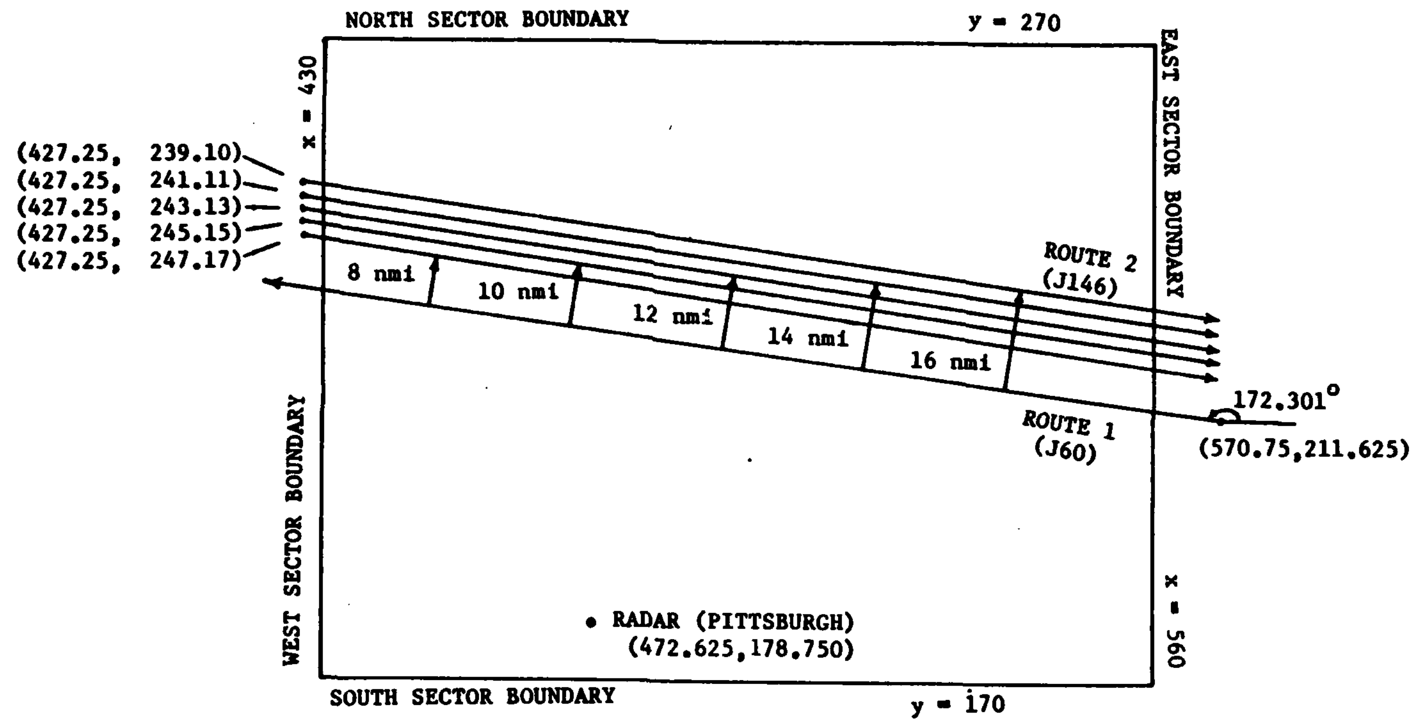


FIGURE 4-2
ROUTE STRUCTURE FOR OPPOSITE DIRECTION
INTERVENTION RATE SIMULATION

simulation so that the effective duration is nearer to three hours. The particular parameters for the NAS tracker and the conflict alert function can be found in Appendix C and G of Volume II of Reference 7 respectively. A flow rate of 5 aircraft per hour on each route was assumed. This very high flow rate for the opposite direction traffic on the adjacent route was selected to demonstrate that under even such unusually high loadings the controller intervention rate would not be unacceptably high. It was also of interest to have a point of comparison with the analysis of same direction traffic flows which considered rates of this order of magnitude. Of course, intervention rate estimates for lower flow rates are obtainable with the simulation.

4.2.2 Results

Ten replications of the simulation were run for each route spacing. The resulting number of Conflict Alerts for each hour of sector operation at the assumed traffic densities is shown in Figure 4-3. The results in Figure 4-3 say that based on the output of the simulation,the average intervention rate for a particular route spacing is given by the points on the line. Furthermore, based on the output of the simulation 95% confidence intervals are shown in Figure 4-3 by the brackets. The important result from the simulation is that at a flow rate of 5 aircraft per hour on each route (which is extremely high for adjacent opposite direction routes at the same altitude) and for a 8 nmi route spacing, on average the expected intervention rate should be less than 1.5 per hour of sector operation.

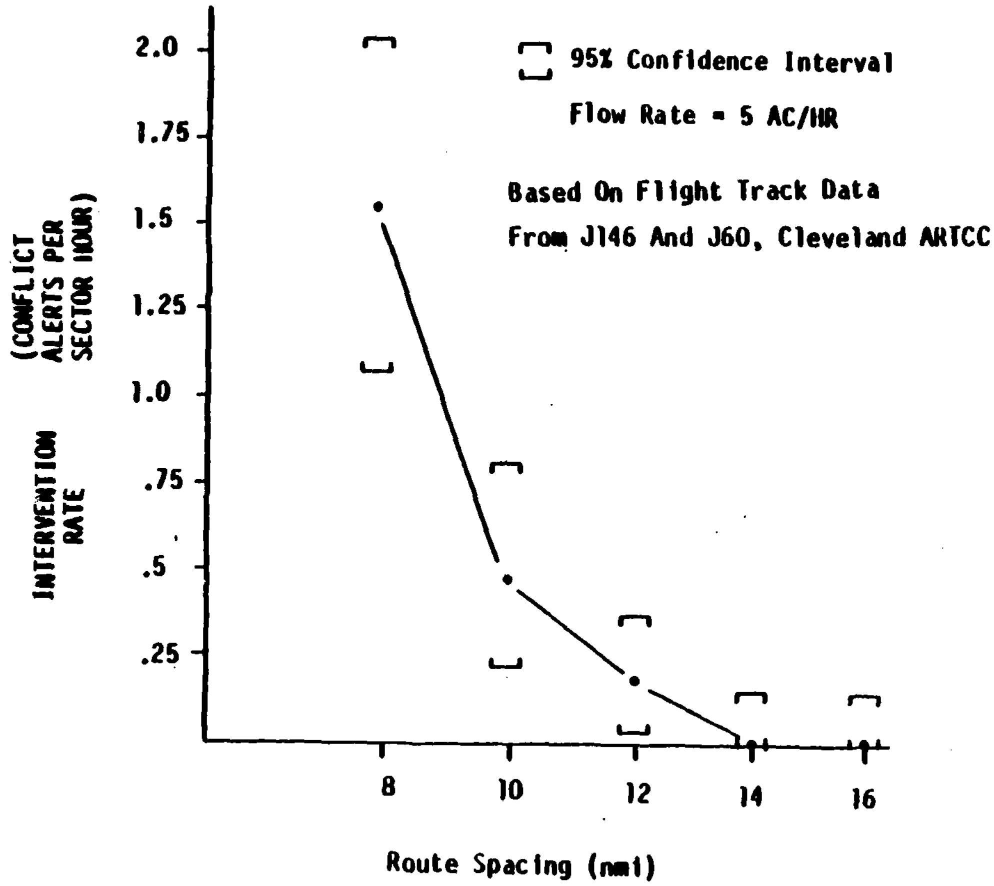


FIGURE 4-3
OPPOSITE DIRECTION
INTERVENTION RATE RESULTS

5. RECOMMENDATIONS

5.1 Conflict Monitoring Analysis Development

It is recommended that the development of the Conflict Monitoring Analysis be extended to include:

a. The addition of conflict encounters involving accelerated flight to the opposite direction traffic analysis. The simulation of the conflict alert intervention rate has shown that accelerated flight trajectories do contribute to conflict alerts.

b. An augmentation of the analysis. This augmentation should include the consideration of:

   - Altitude transitioning traffic along the route, and

   - Converging traffic

5.2 Use of the Analysis

The participants of the FAA's VOR-defined route separation program and the FAA committee which is investigating new route spacing criteria should come to a consensus on representative values for the parameter values which are used in this type of analysis. Also there needs to be agreement on the method of averaging the probability of horizontal overlap over the length of the route and over the various centers. Additionally, there may be a need to collect data to get an estimate of representative flow rates on the routes. This additional data will be needed to judge the extent to which aircraft were censored from the large data base because they were vectored or did not fly the entire route segment. If a probability of horizontal overlap measure is to be used in assessing the safety of specific route spacings, then a method of judging the acceptability of this measure should be defined.

5.3 Additional Areas of Investigation

The methodology described above necessarily estimates the average probability of horizontal overlap or equivalently the average flow rates that can be supported. It does not consider the overlap for each definable situation that could happen between a pair of aircraft. In order to gain a more direct evaluation of the effectiveness of a surveillance based control

system, other measures of system performance should be investigated. These other measures might include the frequency of a risk associated with periods of navigation system failure or ATC system failure, the frequency of and risk associated with periods of well above average traffic loads on parallel routes, and the risk associated with specific aircraft blunder situations.

If for certain traffic densities and for certain route spacings, a surveillance function is required, the implications of this requirement should be investigated. Investigation should include the question of surveillance/automation system reliability as well as the procedures to be used by controllers when the surveillance-based conflict monitoring function has failed or is otherwise unavailable.

APPENDIX A

REFERENCES

1. Flener, William M., "Request for E&D Effort," Letter from the FAA Associate Administrator for Air Traffic and Airway Facilities to the FAA Associate Administrator for Engineering and Development, November 9, 1976.

2. "Preliminary Report on the Results of the Data Collection to Determine Lateral Pathkeeping of Aircraft Flying CONUS VOR-Defined Jet Routes." FAA Technical Center, Radio Technical Commission for Aeronautics Paper No. 291-79/SSRG-35, Altantic City, N. J., November 1979.

3. "Preliminary Recommendations Concerning Improvements to the Current Methodology for Spacing Parallel Jet Routes in a Strictly Strategic Air Traffic Control Environment." FAA Technical Center, Radio Technical Commission for Aeronautics Paper No. 292-79/SSRG-36, Atlantic City, N. J., November 1979.

4. Polhemus, N. W., "Introduction to a General Collision Risk Model for Intersecting and Nonparallel Routes." Princeton University, Radio Technical Commission for Aeronautics Paper No. 9-79/SSRG-27, Princeton, N. J., January 1979.

5. "Terms of Reference -- Separation Study Review Group." Radio Technical Commission for Aeronautics Paper No. 46-77/EC-739, Washington, D. C., March, 1977.

6. "Summary Report of the Separation Study Review Group." Radio Technical Commission for Aeronautics, Paper No. 92-81/EC-854, Washington, D. C., March 20, 1981.

7. Smith, A. P., "Interim Report on the Conflict Monitoring Analysis of Parallel Route Spacing in the High Altitude CONUS Airspace." The MITRE Corporation, FAA-EM-80-16, Volumes I and II, McLean, Va., July 1980.

8. Smith, A. P., "Interim Report on the Conflict Monitoring Analysis of Parallel Route Spacing in the High Altitude CONUS Airspace with Opposite Direction Traffic Flows." The MITRE Corporation, WP-81W00362, Volume II, Washington, D. C., To Be Published.

9. Hauser, S. J., et. al., "En Route Conflict Resolution Advisories: Functional Design Specification Coordination Draft." The MITRE Corporation, MTR-80W00137, McLean, Va., April 1980.

10. George, P. H., Johnson, A.E., and Hopkin, V. D., "Radar Monitoring of Parallel Tracks -- Automatic Warning to Controllers of Track Deviations in a Parallel Track System." Eurocontrol Experiemental Center Report No. 67 (Task C21/1), September 1973.

11. Busch, A. C., Colamosca, B., and Vander Veer, J. R., "Collision Risk and Economic Benefit Analysis of Composite Separation for the Central East Pacific Track System." FAA Technical Center, FAA-EM-77-5, Atlantic City, N. J., June 1977.

12. "Manual On The Use of the Collision Risk Model (CRM) For ILS Operations." ICAO Doc. 9274-AN/904, First Edition, 1980.

MITRE Department
and Project Approval: Balraj G. Sokkappa

Dr. Balraj G. Sokkappa

LME

8